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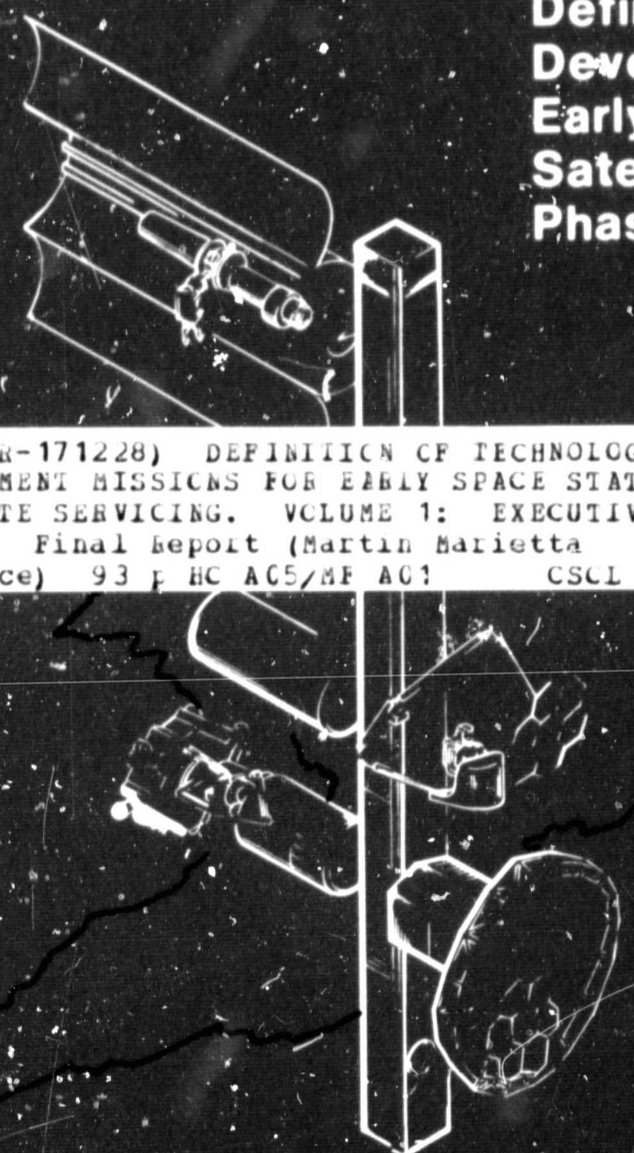
Volume

Executive
Summary

November 1984

Definition of Technology Development Missions for Early Space Station Satellite Servicing Phase 2—Final Report



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Volume I	Executive Summary	November 1984

DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATION SATELLITE SERVICING PHASE 2—FINAL REPORT

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FOREWORD

This final report, submitted to National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), presents the results of the Definition of Technology Development Missions for Early Space Station - Satellite Servicing performed by Martin Marietta Aerospace under NASA Contract NAS8-35042.

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FIGURES

FIGURES (Continued)

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TABLES

ACRONYMS

AXAF	Advanced X-Ray Astrophysics Facility
CCTV	Closed Circuit Television
C&DH	Communications and Data Handling
CDR	Critical Design Review
DDT&E	Design, Development, Test and Evaluation
ECLSS	Environmental Control/Life Support System
EMU	Extravehicular Mobility Unit
EOS	Electrophoresis Operations in Space
EVA	Extravehicular Activity
GD	General Dynamics
GDA	General Dynamics Aerospace
GEO	Geosynchronous Earth Orbit
GFE	Government Furnished Equipment
GN&C	Guidance Navigation and Control
GPS	Global Positioning System
GRO	Gamma Ray Observatory
HEC	High Energy Change
HEO	High Earth Orbit
HRDS	High Resolution Dispersive Spectrometer
IOC	Initial Operational Capability
IOSS	Integrated Orbital Servicing System
IRD	Independent Research and Development
IS	Intelligent Servicer
IVA	Intravehicular Activity
LDR	Large Deployable Reflector
LEC	Low Energy Change
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LOS	Line of Sight
LRI	Low Resolution Imager
LRS	Low Resolution Spectrometer
LRU	Lowest Replaceable Unit
LVLH	Local Vertical Local Horizontal
MDAC	McDonnell Douglas Astronautics Corporation
MFR	Manipulator Foot Restraint
MMC	Martin Marietta Corporation
MMU	Manned Maneuvering Unit
MPP	Materials Processing Platform
MRR	Maintenance Repair and Retrofit
MRS	Moderate Resolution Spectrometer
MSFC	Marshall Space Flight Center

ACRONYMS (continued)

NA	Not Applicable
NASA	National Aeronautics and Space Administration
OMV	Orbital Maneuvering Vehicle
ORU	Orbital Replacement Unit
OTV	Orbital Transfer Vehicle
PDR	Preliminary Design Review
P/L	Payload
PMD	Propellant Management Device
POCC	Payload Operations Control Center
PRC	Planning Research Center
QD	Quick Disconnect
RCS	Reaction Control System
RF	Radio Frequency
RMS	Remote Manipulator System
S/C	Spacecraft
SDR	Software Design Review
SFMD	Storable Fluid Management Demonstration
SFRMS	Servicing Facility Remote Manipulator System
SOW	Statement of Work
SPAS	Shuttle Pallet Satellite (German)
SRA	Systems Requirements Analysis
SS	Space Station
SSGC	Space Station Ground Control
SSMC	Space Station Mission Control
SSMCC	Space Station Mission Control Center
SSRMS	Space Station Remote Manipulator System
ST	Space Telescope
STS	Space Transportation System
TD&FE	Technology Development and Flight Experiment
TDM	Technology Development Mission
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TMS	Teleoperated Maneuvering System
UARS	Upper Atmosphere Research Satellite
XGP	Experimental Geostationary Platform
3-D	Three Dimension

1.0 EXECUTIVE SUMMARY

1.1 Introduction

The Executive Summary includes an overview of both phases of the Definition of Technology Development Missions for Early Space Station Satellite Servicing. The Phase 1 contract was completed during the period of October, 1982 through May, 1983. Phase II, an 18 month contract extension was initiated in June, 1983, and completed in November 1984. The approach and summary results for both will be presented serially, beginning with Phase 1.

1.2 Phase 1 Overview

1.2.1 Purpose of Satellite Servicing Study Phase 1

The primary purpose of Phase 1 of the Marshall Space Flight Center (MSFC) Satellite Servicing Phase 1 study was to establish requirements for demonstrating the capability of performing satellite servicing activities on a permanently manned Space Station in the early 1990s. At the start date of Phase 1, October 1982, NASA was exploring means of acquiring a cognitive perspective of what constituted "satellite servicing." The study would then clarify which satellite servicing task could be beneficially performed at the Space Station and what would be required at the station to enable servicing.

1.2.2 Scope of Phase 1

The scope of Phase 1 included TDM definition, outlining of servicing objectives, derivation of initial Space Station servicing support requirements, and generation of the associated programmatic schedules and cost. NASA MSFC had established, at the beginning of Phase 1, three basic satellite servicing concepts: 1) Modification of the space Station itself during its evolution: 2) repair and or upgrading of satellites onorbit: and 3) assembly of large spacecraft, whose volume configuration would exceed the STS payload capability of one individual flight. All TDM definition and associated analyses were based on these three servicing concepts. The study results for Phase 1 were reported in a two volume report in May, 1983, entitled Definition of Technology Development Missions for Early Space Station Satellite Servicing. The results of Phase II is presented in two volumes. An Executive Summary of Phase 1 and Phase 2 is presented in Volume I. Volume II contains the Technical Report of the approach and results of the Phase 2 study.

1.2.3 Objectives of Phase 1

The primary objectives of the Satellite Servicing Phase 1 study were three in number. The first was to define satellite servicing and establish Space Station requirements relative to providing servicing capability, using Space Station as a "test bed". The second major objective was to establish a technology development plan to describe: 1) basic technology development and tests; 2) Space Transportation

System (STS) zero-gravity validation tests, and 3) Space station servicing validation tests, to provide a technology roadmap for satellite servicing. The final objective was to conceptually define a set of TDMs that would demonstrate an effective capability to demonstrate an operational satellite servicing capability in the late 1990s.

1.2.4 Approach to Conduct of Phase 1

The results of this study were developed by performing the analyses as shown in the Satellite Servicing study flow. Figure 1.2.4-1. This study flow is consistent with the requirements of the contractual tasks identified in the statement-of-work. These three tasks are as follows:

1) Task 1-Mission Requirements - The purpose of this task was to identify satellite servicing and maintenance capabilities from which requirements and servicing objectives could be derived. The analyses emphasized by this task was the development of a satellite servicing data base, consisting of a time phased satellite servicing mission model, the development of potential servicing tasks and locations (servicing scenarios) and associated Mission/System/Detailed Objectives, the development of system and hardware accommodation requirements and the identification of technology capability needs and development.

2) Task 2 Mission Definition - The purpose of this task was to develop Technology Development Mission (TDMs), establish their operational requirements and accommodation needs that will satisfy the requirements and servicing tasks developed by Task 1. The analyses emphasized were: 1) the development of the capability to perform routine satellite servicing tasks from the early space station; 2) the evaluation of the operational concepts and approaches to identify operational requirements and hardware; and, 3) the evaluation of accommodation needs, special servicing equipment required on the space station to accommodate the satellite servicing capability and the identification of satellite, space station, and servicing hardware interfaces.

3) Task 3 Programmatic Analysis - The purpose of this task was to generate the plans, schedules, and costs for implementation of the TDMs. The analyses emphasized were space station capability evolution, satellite servicing economic benefits, precursor technology capability schedules, TDM performance schedules, and the associated TDM costs.

1.2.5 Ground Rules and Guidelines for Phase 1

The following ground rules and guidelines were provided by NASA MSFC to guide the efforts conducted within this contract.

a. Maximum utilization was made of applicable data and results from prior and current projects and government sponsored studies.

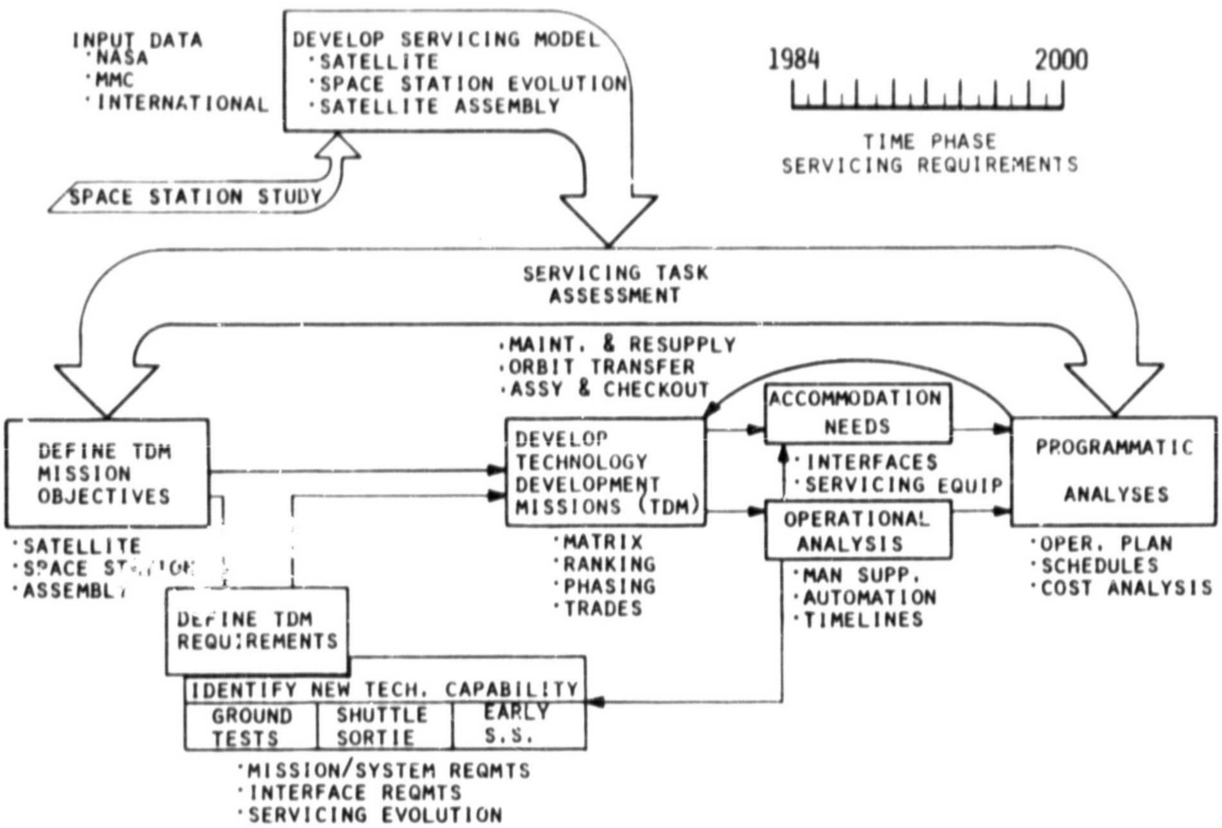


Figure 1.2.4-1 Satellite Servicing Study Flow

b. The Space Shuttle was considered as the earth launch vehicle and the Space Station user's Handbook was used to provide the associated guidelines.

c. An early Space Station will be operational in 1990.

d. An Orbital Maneuvering Vehicle (OMV) will be available to support onorbit operations.

1.3 Summary Results of Phase 1

The overall objective of the Space Station Satellite Servicing study was to define the evolutionary development of a satellite servicing capability on a permanent manned space station in the early 1990s, and to conceptually design Technology Development Missions (TDMs) to demonstrate the satellite servicing capabilities on the early space station. This objective was met with the selection and validation of eight TDMs designed t satisfy the four derived servicing tasks of assembly, orbit transfer, resupply, and maintenance. Completion of these time phased TDMs demonstrated a satellite servicing capability to perform the servicing tasks at or remote from the space station so that satellite servicing can become a routine activity from the early space station. Three tasks were accomplished during the course of this study to achieve the results necessary to accomplish the study objective, these tasks are; Task 1 - Mission Requirements, Task 2 - Mission Definition, and Task 3 - Programmatic Analysis. The summaries of these three tasks are as follows:

1.3.1 Task 1 Mission Requirements

The analyses included in this task are; a satellite servicing data base, servicing task and location (scenarios), evaluation of the servicing scenario requirements and the identification of objectives and capabilities needed to accomplish the servicing tasks. Mission model analysis revealed a broad range of servicing tasks. The Martin Marietta Space Station Satellite Servicing Mission Model identified 185 satellite systems existing and/or planned for operations during the decade of the 1990s, with 387 servicing tasks projected during the early space station period, reference Figure 1.3.1-1. Servicing task and location assessment (servicing scenarios) produced four major task areas that subdivide into 10 associated subtasks, as shown on Figure 1-3.1-2. These tasks and subtasks are:

1) Assembly - space station assembly and onorbit assembly of large spacecraft;

2) Orbit transfer - delivery and retrieval of spacecraft to and from operation orbits using the space station as a base of operations;

3) Resupply - resupply of fluids (earth storable and cryogens) and material (logistics, modules, raw materials, instruments);

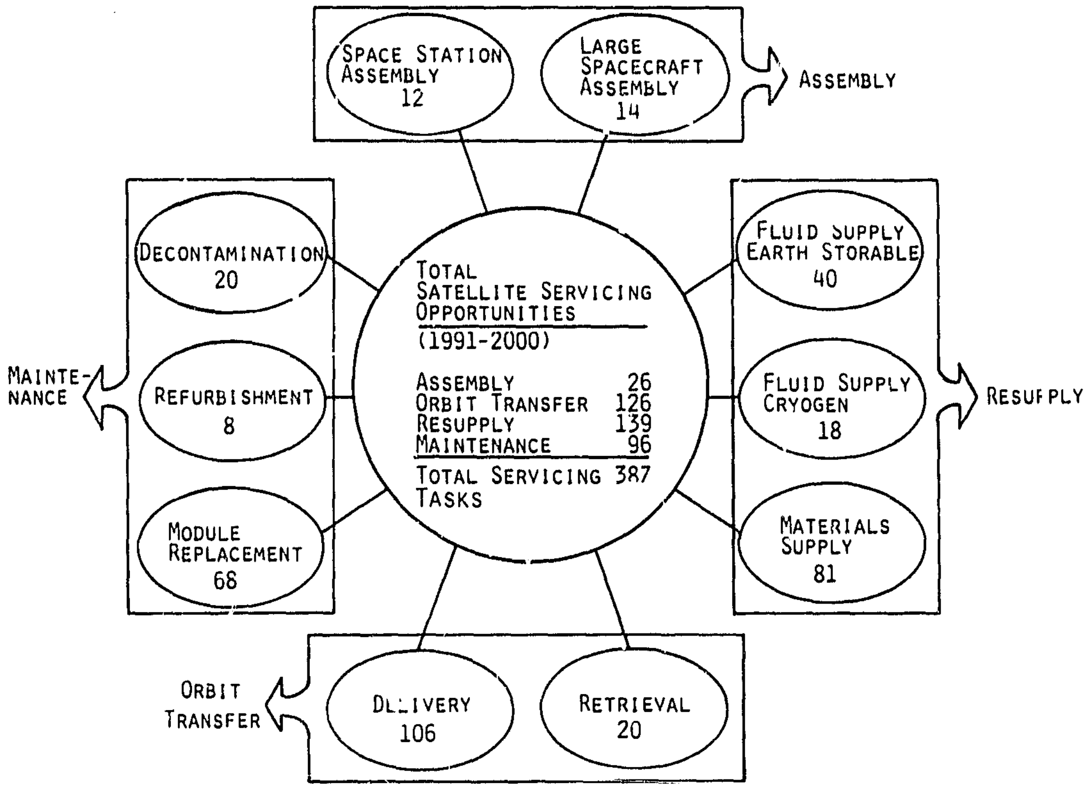


Figure 1.3.1-1 Satellite Servicing Tasks

Servicing Tasks	Servicing Sub-Tasks	Servicing Locations: Space Station	S/C Berthed at S/S	S/C in LEO: S/S Plat.	S/C in LEO: User S/C	S/C in GEO
Large Structures Assembly/Modification	Space Station Assembly/Modification	✓		✓		
	Large S/C Assembly	✓	✓			
Orbit Transfer	Delivery			✓	✓	✓
	Retrieval			✓	✓	✓
Resupply	Fluids - Earth Storable Mono, Bi-Prop	✓	✓	✓	✓	✓
	Fluids - Cryogen	✓	✓	✓	✓	✓
	Mtrls - Logistics Raw Materials	✓	✓	✓	✓	✓
Maintenance -Preventive -Corrective	Module Replacement	✓	✓	✓	✓	✓
	Refurbishment	✓	✓	✓	✓	✓
	Decontamination	✓	✓	✓	✓	✓

Figure 1.3.1-2 OMV/OTV/Satellite Servicing - A Broad Perspective

4) Maintenance - conduct of planned and unplanned repair operations and decontamination operations.

Servicing tasks will be conducted in three locations: 1) on the space station itself; 2) on satellites berthed at the space station; and 3) on satellites remote from the space station in low or high earth orbits.

Mission objectives were developed for each of the four major servicing tasks; assembly, orbit transfer, resupply, and maintenance. From the four top level mission objectives, 21 primary system level objectives and 230 detail level objectives were formulated.

Functional and operational analyses were developed for the servicing tasks and locations (mission scenarios). 112 satellite servicing scenarios were identified, and through an iterative process of cross-checking and comparison these sequences were reduced into a total of 18 functional analyses that included the servicing activities required in performing servicing tasks at all potential servicing locations. These functional analyses resulted in identification of servicing requirements hardware/facilities and technology capabilities required to provide these operational servicing abilities in the early space station era. These requirements include structural and mechanical equipment and facilities, data processing and display, audio and visual communications, handling equipment (such as a Space Manipulator Arm/Space Crane, work stands, hangar extensions, etc), and servicing and storage facilities for transfer vehicles and servicers. The development of satellite servicing integrated requirements and their functional analysis for the TDMs was accomplished in parallel with this study but these efforts were funded through Independent Research and Development.

1.3.2 Task 2 - TDM Mission Definition - Phase 1

A Technology Development Mission (TDM) demonstrates a specific satellite servicing capability or set of capabilities conducted at or initiated from the Space Station. The TDM definition task results were produced by using the output of the servicing task assessment. For each of the major servicing task categories, mission-level, system-level and detail-level objectives were defined, with over 200 servicing objectives identified. The derived objectives provided a starting point for identification of TDM scenarios. Referring to Figure 1.3.2-1, three analyses tasks; 1) mission objectives definition, 2) servicing task/location assessment, and 3) identification of task performance techniques, were used as inputs to the process of identifying specific potential satellite servicing scenarios.

The TDM Definition process was supported directly by the resultant identification of 112 unique servicing scenarios. These scenarios were specific time-phased sequences of servicing events, describing candidate satellite servicing missions. From the 112 servicing scenarios, it was determined that all of the servicing tasks, using the various servicing techniques, could be assessed for TDM selection applicability, Space Station requirements definition and technology development, by conducting 18 different functional analyses.

A top level example of these analyses is shown at Figure 1.3.2-2. This functional analysis highlights the scenario/servicing task of performing an orbit transfer (in this case, payload delivery) to a geostationary orbit, using the low energy OMV and the high energy Orbital Transfer Vehicle (OTV) to deliver a payload using reusable Space Station based upper stages. As shown on Figure 1.3.2-2, Space Station satellite servicing requirements were derived from this analysis, and servicing technology development requirements were identified also.

There were no specific limitations, in the Phase 1 contract, on selection of Technology Development Missions (TDMs). The definition of one or a number of TDMs was left to each contractor. Martin Marietta developed a series of eight TDMs that, if accomplished at or from Space Station, would demonstrate all of the previously identified satellite servicing tasks and cover all locations at which it was considered feasible to conduct servicing activities. As shown in Table 1.3.2-1. These TDMs demonstrated all of the assembly, orbit transfer, resupply, and maintenance/repair servicing operations as shown on Figure 1.3.2-3, the TDM Task/Location Validation Matrix. In fact, on fifty percent of the mission scenarios (4 of the 8), multiple servicing tasks were to be performed.

For the selected TDMs, each was fully described, a servicing objective established, a functional and operational analysis conducted and the specific precursor technologies outlined. This level of technical description and assessment enabled clear and concise comprehension of how satellite servicing could be demonstrated, using the early Space Station as an operational test bed.

1.3.3 Task 1 Mission Definition - Requirements Derivation - Phase 1

The second phase of the Mission Definition task was to derive servicing requirements. The two phases of functional analyses: 1) analysis of the 18 servicing scenarios, and 2) functional and operational analyses of the eight selected TDMs, provided valuable technical assessments of the types of servicing elements, i.e., service hangars, storage facilities, transfer mechanisms and orbital transfer vehicles that would be required at a Space Station to enable performance of satellite servicing activities.

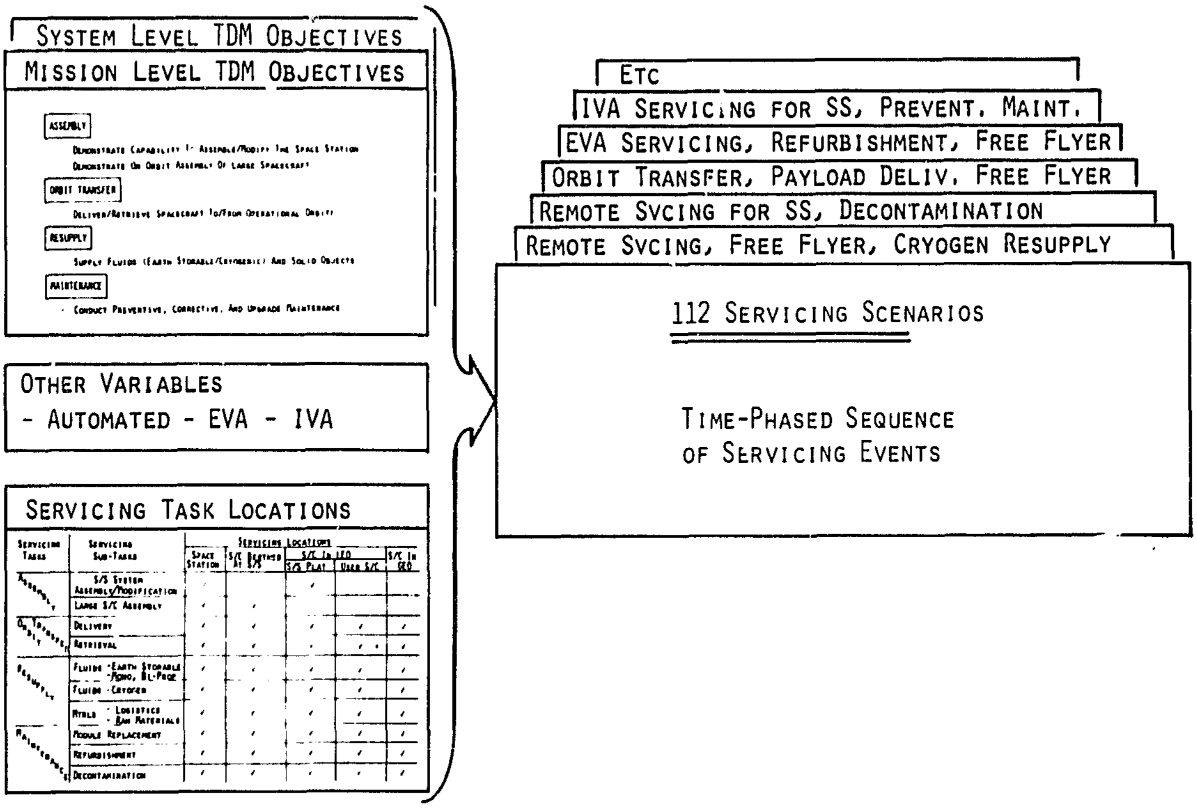


Figure 1.3.2-1 Mission Scenarios

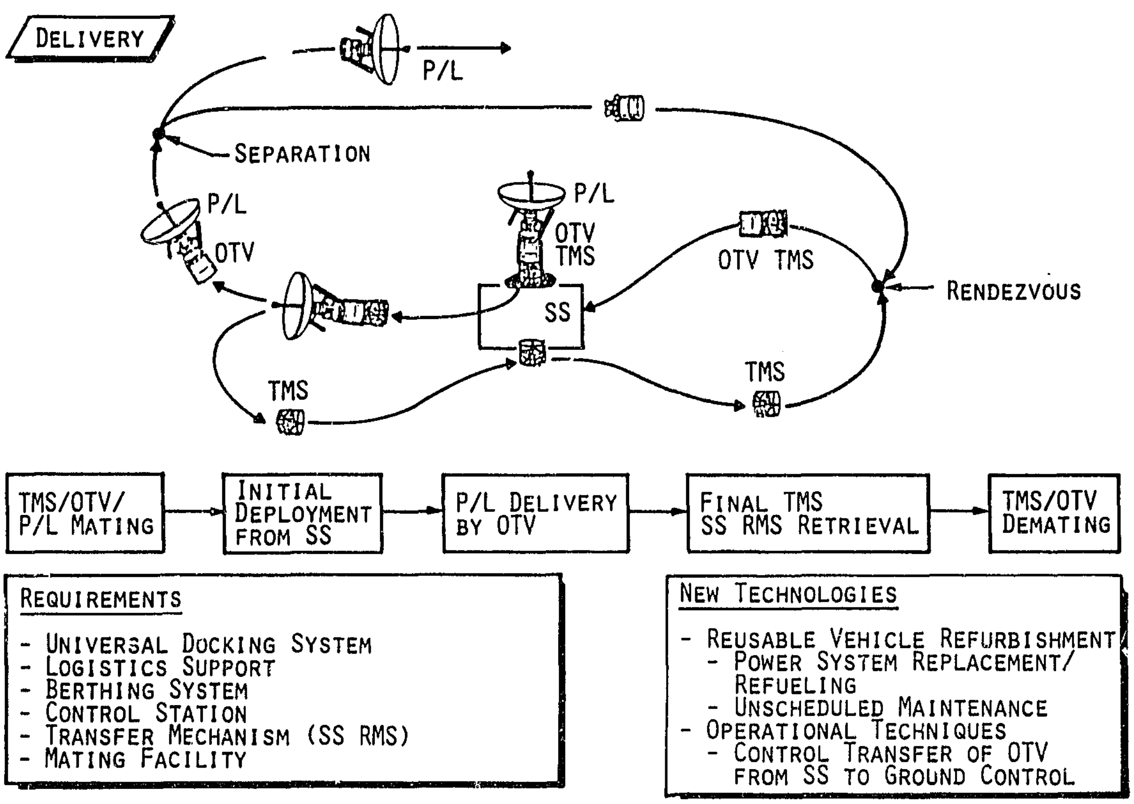


Figure 1.3.2-2 Functional Analysis Example - Orbit Transfer, P/L Delivery

Table 1.3.2-1 Satellite Servicing TDMs

TDM	OBJECTIVE
1	SPACE STATION ASSEMBLY, MODIFICATION, RESUPPLY AND MAINTENANCE
2	LEO TRANSFER RESUPPLY AND RETRIEVAL (SOLID OBJECTS)
3	ORBIT TRANSFER (GEO DELIVERY)
4	LARGE SPACECRAFT ASSEMBLY
5	RESUPPLY (CRYOGENS)
6	MAINTENANCE/DECONTAMINATION (EVA)
7	MAINTENANCE/MODULE(S) REPLACEMENT AND FLUID RESUPPLY (GENERAL PURPOSE ROBOTIC SERVICER)
8	RESUPPLY (FLUIDS AT GEO)

Task		Location: Space Station	Location: Remote From Space Station — LEC	Location: Remote From Space Station — HEC
Large Structure Assembly/ Modification	Space Station Assembly/Maint	TDM 1	NA	NA
	Spacecraft Assembly	TDM 4	NA	NA
Orbit Transfer	Delivery	NA	TDM 2 4,5,6,7	TDM 3 8
	Retrieval	NA	TDM 2 6,7	NA
Resupply	Fluids Earth Storable	TDM 1 2,3,4,5,6,7,8	TDM 8	
	Fluids Cryogen	TDM 1 3,4,5,7,8	TDM 5	
	Materials, Large Modules	TDM 1 2	TDM 2	
Maintenance	Module Replacement	TDM 6,7	TDM 2	
	General Maintenance	TDM 6,7		NA
	Decontamination	TDM 6		NA

LEC - Low Energy Change
HEC - High Energy Change

Figure 1.3.2-3 TDM Operation Validation Analysis

An outline of Phase 1 derived Space Station requirements is shown at Figure 1.3.3-1. These requirements/accommodations provide a top level view of the need for a servicing facility to perform extensive satellite maintenance and repair activities. This "service hangar" would require attachment/stabilization equipment, (including a recommended rotatable carousel mechanism to rotate satellites for servicing), translatable work stations (to enable astronaut access to the entire satellite), and other support elements such as CCTV, communications, lighting, and life support monitoring. As shown, many servicing elements will require storage, others will require berthing and many will require transport around the Space Station facility. These top level requirements were used subsequently to derive conceptual Space Station accommodations and these design concepts will be presented in a proceeding paragraph of this summary report.

1.3.4 Task 1 Mission Definition - Technology Development Plan - Phase 1

A third TDM mission definition task element related to technology development. The objective of the task was to determine those technology areas that would require new starts to enable development of satellite servicing capability on the Space Station. Another objective was to outline a phased plan to ensure that the needed technology was scheduled, within the time frame that would lead to development of the systems and equipment essential to providing satellite servicing capability in the early 1990's. Top level satellite servicing technology development issues were determined during functional analyses of the servicing scenarios and the eight TDMs.

A review of servicing technology produced a set of "key technology issues", related specifically to satellite servicing, as shown in Figure 1.3.4-1. These technology areas include, orbital fluid transfer, OMV, OTV, onorbiter maintenance, servicers, and space automation. The servicing task of orbit transfer, either low or high energy delivery or retrieval, requires solutions to onorbit fluid transfer management issues, for both earth storable and cryogenic fluids. These issues include mass measurement, measurement accuracy, quick disconnects for zero spill (contamination reduction), propellant management device (PMD) validation, and standard fluid transfer interfaces for servicing ease and efficiency. The development of space-based, reusable high energy (OTV) and low energy (OMV) Space Station transport vehicles establishes an additional complex set of technology development requirements, including, autonomous rendezvous, teleoperated docking of OMV and other spacecraft, an OTV aerobrake and perhaps an advanced, throttleable OTV engine. The need to refurbish both OMV and OTV onorbit, mandates maintainability considerations, equipment grouping for ease of removal/replacement, and automation of repetitive operations for efficiency and reduction of EVA time, the demand for which is anticipated to be high. Technology issues for each of the seven related areas were identified and included in the Technology Development Plan.

Satellite Servicing				Reusable OMV/OTV
Service Facility	**Storage Facility**	**Berthing Systems**	**Transfer Mechanisms**	**Reusable OMV/OTV**
– Safety Equipment – Module Changeout Eqpmt/Fixtures – Assembly Facilities – Mating/Demating Mechanisms/Devices – Alignment Eqpmt – Spacecraft/Transfer Vehicle/SS RMS/MMU Checkout Eqpmt – Clean Room(s) – Thermal Control/ Meteoroid Protection – Payload Cradle/Carousel Mechanism – Work PLatforms – Lighting Aids – Foot Restraints/ Handholds – Contamination Shields – Communications – CCTV – Voice – Command/Telemetry Via TDRSS Through SSMC – GPS Data Reception – Life Support Monitoring	– Replacement Parts – Tools/Equipment – Fluids – Earth Storable – Cryogens – Pressurant Gases	– Spacecraft Elements – TMS/OTV – Servicers – Storable Fluids – Cryogens – Modules – Maintenance – Decontamination – MMU – Grappling Mechanism – System Status Monitoring Eqpmt	– Space Station RMS – OMV, OTV – MMU/EMU (EVA) – Space Station RMS Track – OMV, OTV, SS RMS Servicers – Data Display – Data Storage – Data Processing Control	– Berthing Station – Resupply Station – Refurbishment Station – Service Facility – Transfer System – SS RMS Track – Command/Control – SS MC Console – Mating/Demating with Servicers/ Spacecraft – Service Facility

Figure 1.3.3-1 Functional Analysis - Derived Requirements

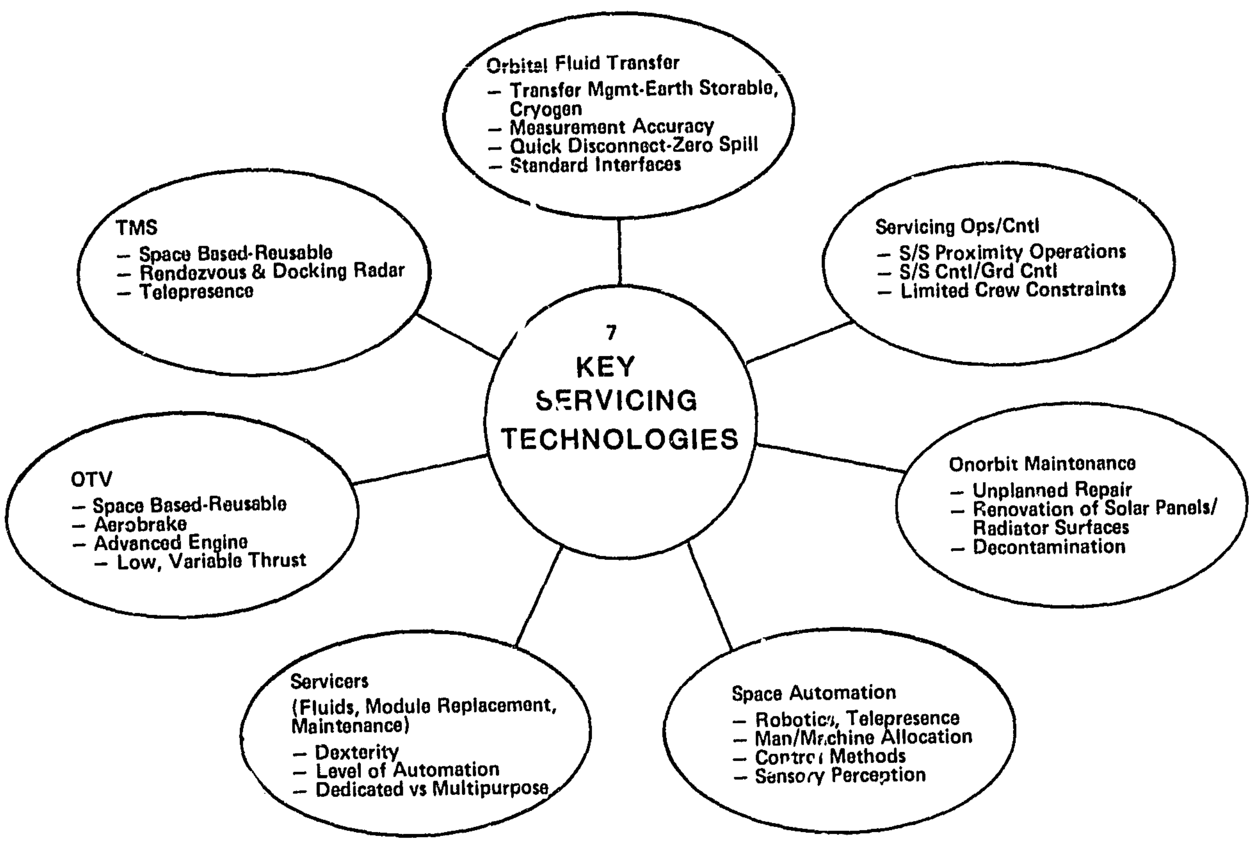


Figure 1.3.4-1 Key Technology Issues Identified

For each identified technology development area, a specific evolutionary schedule of technology development activities was prepared. The technology plan for fluid transfer capability evolution is shown in Figure 1.3.4-2.

The required technology development for both earth storable and cryogenic fluids is presented. Ground development for earth storable fluids included resolution of some of the previously discussed fluid management transfer issues.

Work underway at Martin Marietta included independent research and development (IR&D) on the design of an experimental Space Transportation System (STS) fluid supply system and the study of onorbit fluid transfer phenomena.

Also shown in Figure 1.3.4-2 are the STS flight experiments either already planned by NASA or recommended as fluid transfer management "zero gravity" validation of ground developments. Martin Marietta, in another IR&D program has developed a Storable Fluid Management Demonstration (SFMD) device, to transfer fluids in the Orbiter mid-deck between calibrated supply and receiver tanks, and NASA has scheduled the SFMD experiment on a 1984 flight. A NASA cargo bay demonstration had been scheduled at the time of the Phase 1 effort and that experiment was conducted successfully during October, 1984. Martin Marietta has recommended a cargo bay experiment to transfer propellants from a multiple set of Shuttle reaction control system (RCS) tanks to a Mark II propulsion module, and this experiment, demonstrating onorbit transfer capability using proven flight systems, designed for transfer, would serve to extend confidence in potential users of the eventual routine capability to conduct satellite life extending onorbit propellant/pressurant resupply. Experiment was recommended to be conducted in 1987.

Further recommended onorbit fluid transfer validation tests included STS fluid transfer tests of the Teleoperated Maneuvering System (TMS) now OMV, using fluid tanks specifically designed for OMV onorbit fluid resupply.

Finally, Space Station fluid transfer validation tests must be conducted, including checkout of a Space Station fluid resupply depot, to demonstrate capability to receive and store fluids on orbit and to be able to transfer fluids to OMV and to other spacecraft requiring fueling.

Cryogenic fluid transfer technology development requirements are even more complex and will require extensive ground development efforts to resolve the critical problems of transferring super-cooled fluids onorbit. Martin Marietta is presently conducting a preliminary design of the Cryogenic Fluid Management Facility, a test pallet being designed as an STS onorbit laboratory, capable of conducting the full range of cryogenic fluid management experiments required to ensure effective and efficient storage and transfer of liquid oxygen, hydrogen and other supercooled fluids. These experiments are tentatively scheduled for flights commencing in 1987. As is true for storable fluids, recommended Space Station cryogenic fluid transfer validation tests are included in Figure 1.3.4-2.

1.3.5 Task 1 Mission Definition - Satellite Servicing Accommodation Needs - Phase 1

Space Station accommodation needs were generated using the results of requirements derived, during functional analyses of servicing scenarios and TDMs. The identification of specific Space Station requirements, outlined previously in Paragraph 1.3.3, enabled conceptual development and evaluation of Space Station elements and support equipment. A summary of those activities will be presented herein.

TDM 7, Maintenance and Module Replacement, will be used to summarize the process used in developing conceptual accommodation needs. A top level functional analysis of this TDM is presented at Figure 1.3.5-1, highlighting major servicing scenario activities, and derived requirements. The primary servicing objectives of TDM 7 were: 1) to demonstrate retrieval of the Advanced X-Ray Astrophysics Facility (AXAF) from its operational orbit and return to the Space Station; 2) validation of a general purpose robotic servicer in a service hangar, and 3) repair and resupply of AXAF subsystems.

AXAF was chosen primarily because onorbit servicing is a strong feature of this spacecraft's design. As shown in Figure 1.3.5-2, the initial AXAF design includes provisions for replacing a number of spacecraft and scientific instrument modules onorbit, and configuration for accessibility to perform servicing activities.

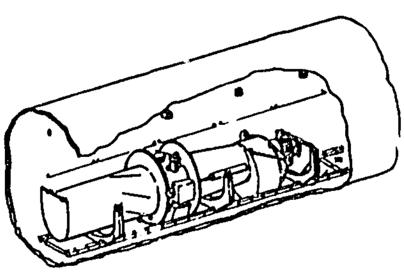
A design concept for the servicing facility needed to accommodate AXAF servicing at the Space Station was developed, taking into account the multiplicity of requirements derived from AXAF and from the other seven TDMs. A view of the overall satellite servicing hangar and a closeup of the interior of the hangar with some of the support equipment is shown at Figure 1.3.5-3. A dominant feature of the enclosed servicing hangar is a carousel mechanism on which the satellite being serviced can be rotated 360°. Also shown is a translatable work station, capable of moving the astronaut around the entire length of the service hangar. Within the service hangar, a payload cradle or carriage mechanism provides support to the AXAF, and lights, video and contamination monitors support the astronaut in performing the complex servicing tasks. Figure 1.3.5-4 provides another concept of a multiple position translation carriage that supports horizontal movement of the astronaut and increases the work volume available while fixed in a foot restraint work platform. This figure displays the potential for automating servicing processes which evolve into frequent, standard work tasks on satellites with multiple interfaces, modular subsystems and Orbital Replacement Units (ORUs). Automation of many servicing activities is feasible, and in fact, automation of some repetitive, hazardous activities, such as propellant resupply of OMV and visiting spacecraft may require automation to remove contamination threats to astronauts performing the mission manually.

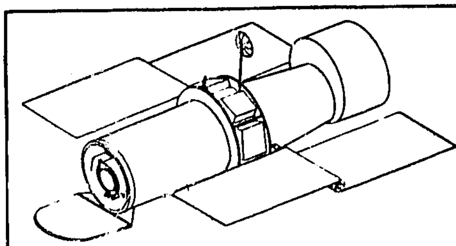
TECHNOLOGY	GROUND	STS	SPACE STATION
ORBITAL FLUID TRANSFER (EARTH STORABLE)	MMC IR&D - ORBITER SUPPLY SYSTEM DESIGN (O) MMC IR&D - PROPELLANT TRANSFER (O) PROPELLANT XFER PROCEDURE DEVELOPMENT (R)	MMC - IR&D STORABLE FLUID MGMT DEMO (P) NASA - HYDRAZINE TRANSFER EXPERIMENT (P) MULTI-MISSION MODULAR SPACECRAFT (MMS) - MARK I PM TRANSFER (R) TMS/MARK II (R) TMS "BATTLESHIP TANK" FLUID XFER TESTS (R) FLUID TRANSFER CONTROL ALGORITHM DEVELOPMENT (R)	TMS/LOGISTICS MODULE FLUID TRANSFER DEMO (R) LOGISTICS MODULE/SS FLUID TRANSFER DEMO (R) TRANSFER CONTROL SYSTEM TEST & DEMO (R)
(CRYOGEN)	MMC IR&D - CRYOGEN TRANSFER & FILL (O) LeRC/MMC - DESIGN OF CRYOGENIC FLUID MGMT FACILITY (CFMF) (O) JSC/MSFC - PROPELLANT DELIVERY TO ORBIT (P) - ET SCAVENGING - AFT CARGO CARRIER - OMS RECOVERY/CAPTURE	CFMF FLIGHTS (P) OTV "BATTLESHIP TANK" FLUID XFER TESTS (R)	SS CRYOGEN STORAGE TANK FILL DEMO (R) OTV/CRYOGEN STORAGE TANK TRANSFER DEMO (R) CRYOGEN TRANSFER CONTROL SYSTEM TEST AND DEMO (R)

C - COMPLETE O - ONGOING P - PLANNED R - RECOMMENDED

Figure 1.3.4-2 Evolutionary Technology Plan-Fluid Transfer

SHUTTLE DOCKING & CARGO TRANSFER TO SS → RETRIEVE AXAF* USING TMS → AXAF GENERAL INSPECTION SERVICING USING ROBOTIC GENERAL PURPOSE SERVICER → RESUPPLY FLUIDS/GASES → REDEPLOY AXAF* TO OPERATIONAL ORBIT USING TMS





OPERATIONAL REQUIREMENTS:
- STS
- SPACE CRANE/RMS
- CRANE/RMS CONTROL CONSOLE
- EMU/MMU
- P/L BERTHING STATION (HANGAR), TOOLS, LOGISTICS
- GROUND/SS CREW COMM & CONTROL
- ROBOTIC GENERAL PURPOSE SERVICER
- AXAF CHECKOUT INSTRUMENTATION
- FLUIDS SERVICING EQUIPMENT
- TMS, OTV, SERVICER } CONSOLE TRADE (SINGLE/MULTI)

*GROUND CONTROL

TITLE:	ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF)
INCLINATION:	28.5°
ALTITUDE:	400 KM/216 NM
S/C MISSION:	ASTROPHYSICS FACILITY FOR DETERMINING X-RAY SOURCES & PHYSICAL PROPERTIES

Figure 1.3.5-1 TDM 7 Maintenance and Module Replacement - Operations Analysis (Example)

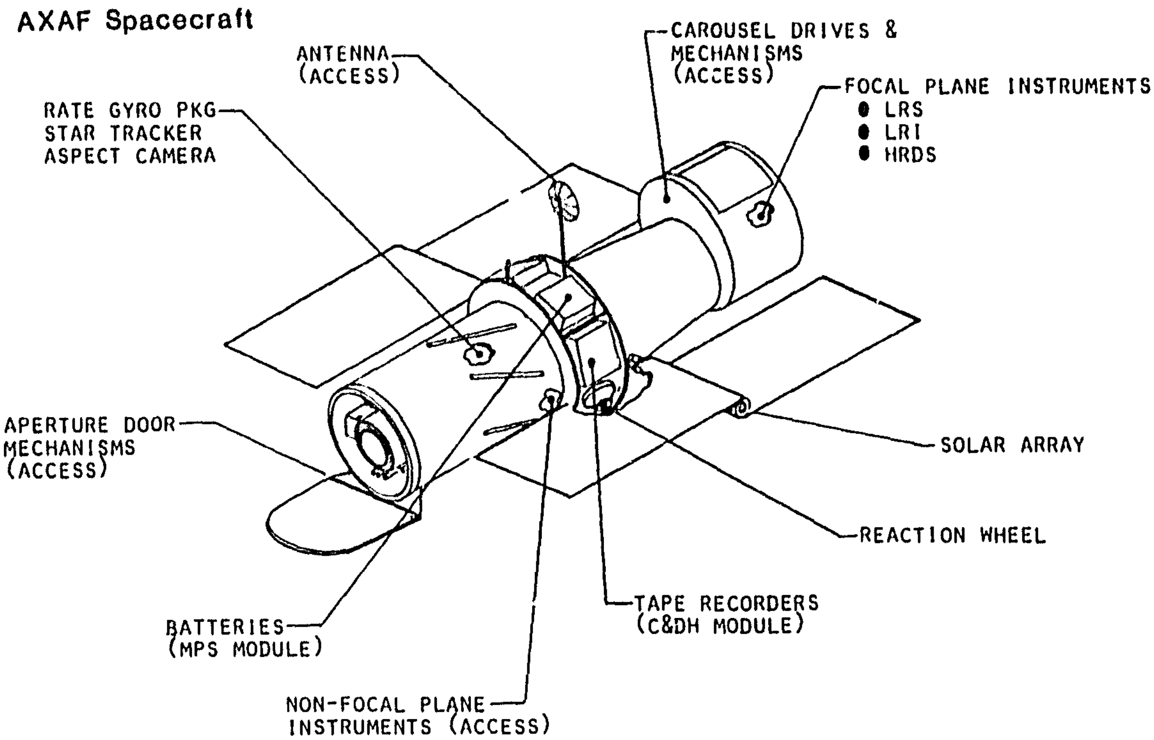


Figure 1.3.5-2 Servicing Requirements

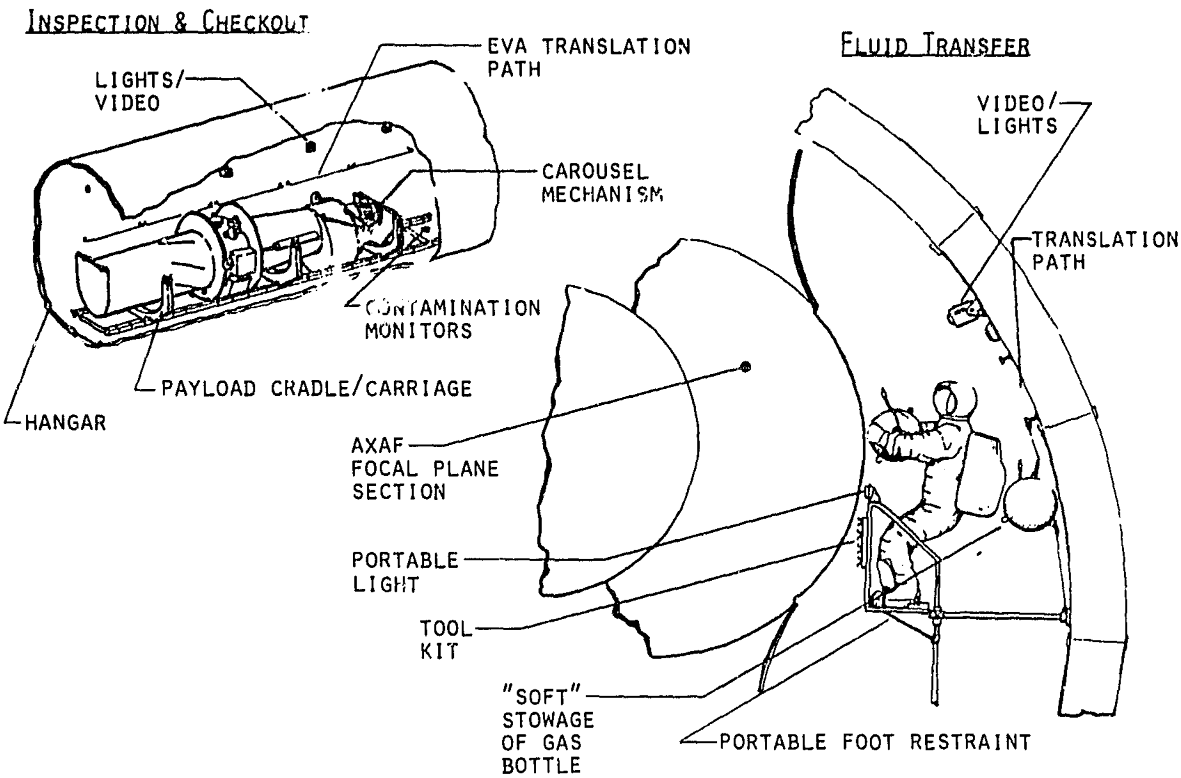


Figure 1.3.5-3 Servicing Activities

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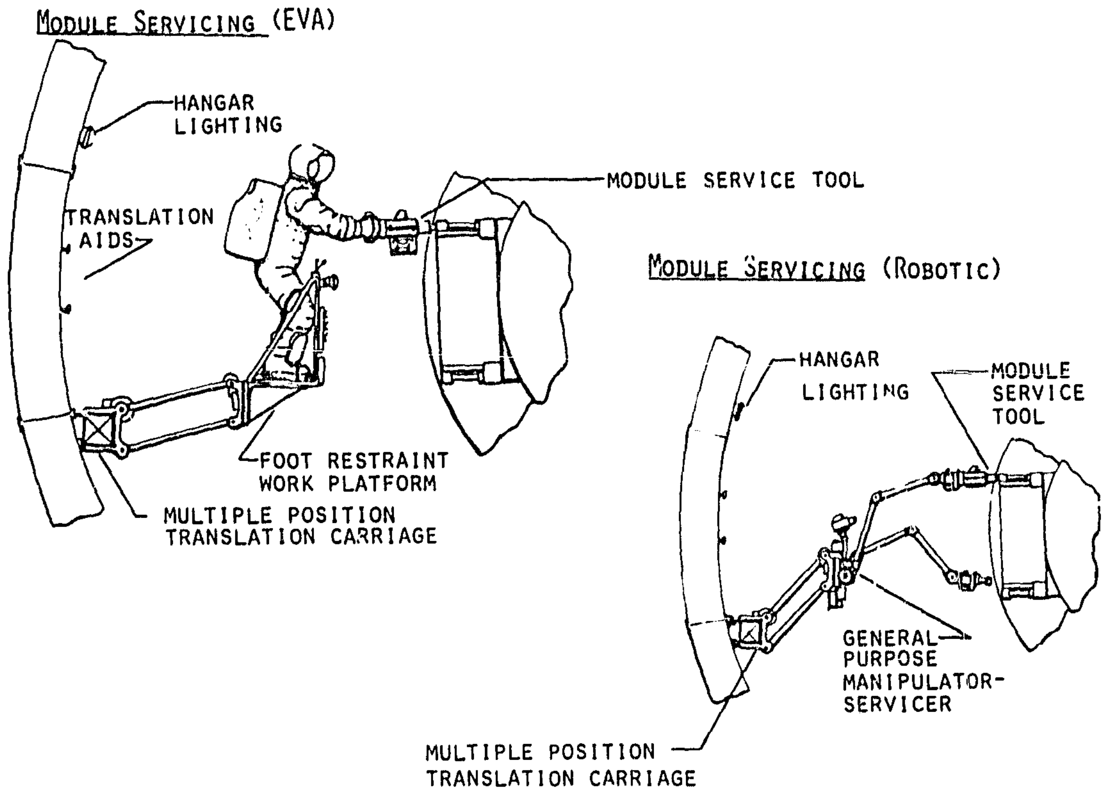

Figure 1.3.5-4 Servicing Activities

1.3.6 Programmatic Analyses - Phase 1

Programmatic analysis activities for the Phase 1 satellite servicing study included an assessment of relative cost/benefit of generic servicing tasks, technology development schedules, TDM schedules and TDM implementation costs.

Economic benefit analyses were conducted comparing servicing based at the Space station versus using the STS to conduct servicing. Results of that analysis are shown in Figure 1.3.6-1. The marginal cost shown is the additional cost of providing the capability at Space Station. Similarly, economic benefits are primarily derived from transportation cost avoidance. These benefits come from avoidance of STS flight costs from earth to orbit and costs incurred in using expendable upper stages. For Space Station delivery and retrieval missions, primary cost benefits are achieved with space-based reusable OMVs and OTVs. From the figure it is clear that delivery of payloads to geostationary orbit provided maximum benefit, low earth orbit servicing and delivery are less cost beneficial, and servicing at GEO provides minimum economic benefit.

A major scheduling activity was the time-phasing of previously identified critical satellite servicing technology development. Through examination of the Technology Development Plan and surveys of the status of various elements of each of the technology issues, an estimate of the time-phasing of technology development was prepared. This technology development schedule is provided in Figure 1.3.6-2. The TMS (OMV) was projected to be available in 1986, during the Phase 1 study period, and as will be seen in the Phase 2 summary, this has changed substantially. The time line for OTV development is shown, and it, too, has changed significantly. Space Automation advances are shown for a Space Station crane, a TMS (OMV) servicer, for remote servicing operations, and finally, a fully automated Space Station general purpose servicer to conduct fully automated operations in the servicing hangar.

A third programmatic study task was to provide an estimate of the relative time in which the eight TDMs could be conducted to demonstrate the capability to perform servicing at the Space Station. This schedule is shown in Figure 1.3.6-3. The assembly of the Space Station satellite servicing support area is the initial TDM, as all other require its completion as a precursor activity. As quickly as the service support area and the reusable OMV are complete and validated, TDMs 2 & 6 can be conducted. In fact, as will be shown in Phase 2, if certain precursor activities are demonstrated on a slightly improved schedule, TDM 7, the AXAF retrieval/repair missions could be performed in late 1991, in case of an early failure of major AXAF components. TDM 8, a mission to resupply fuel on a spacecraft at GEO, will require development and validation of the OTV. It will also require the development and validation of an intelligent front end for OMV capable of conducting remote, teleoperated servicing operations at GEO, and the capability to mate OMV/OTV and fly out and return from GEO. This schedule appeared to be realistic and achievable during the Phase 1 study, assuming appropriate resources were allocated both to required technology development and TDM implementation.

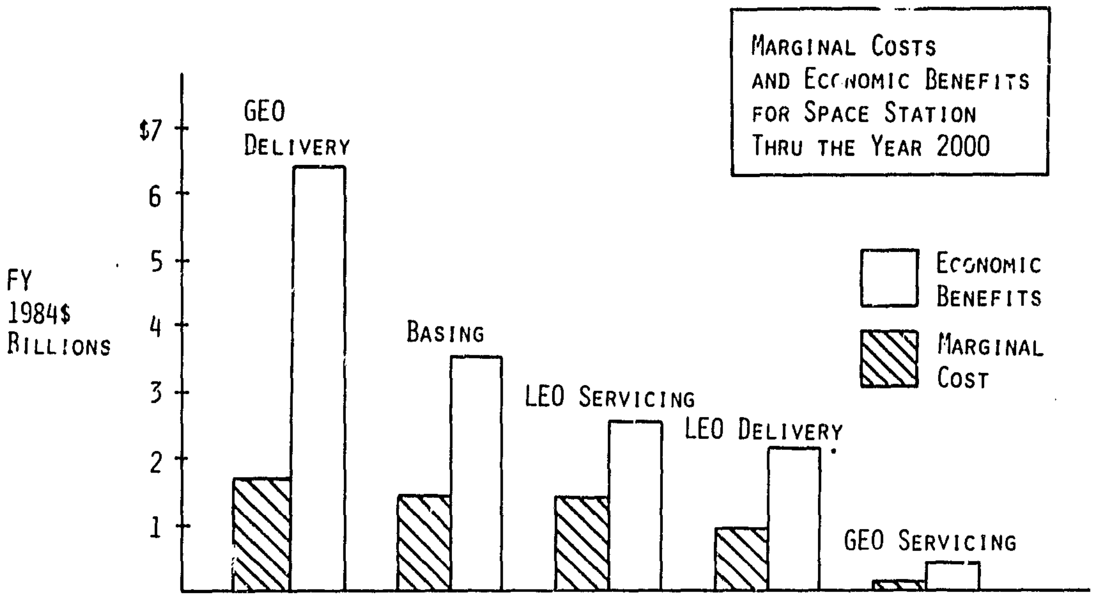

Figure 1.3.6-1 Marginal Costs and Economic Benefits by Capability Increment

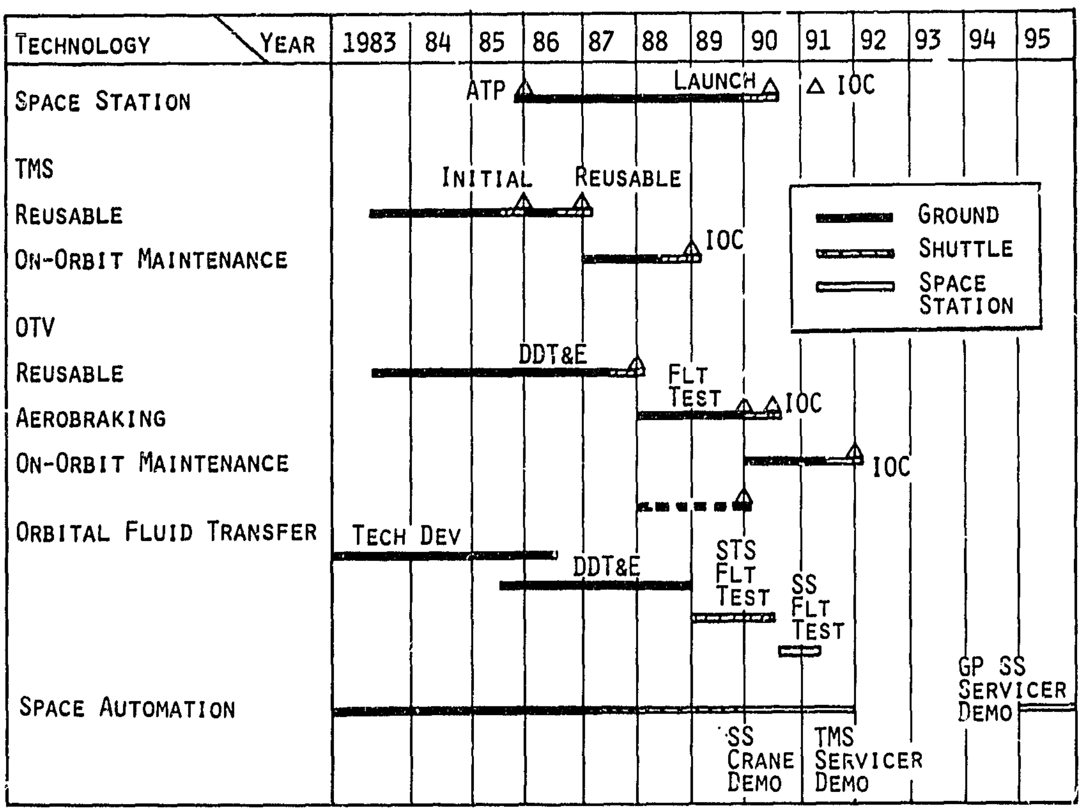

Figure 1.3.6-2 Critical Precursor Technology Schedules

The final cost related study task was to estimate the cost of implementing the TDMs. The Martin Marietta approach to this task is shown on Figure 1.3.6-4. Wherever possible, TDMs were scheduled to be implemented with actual operational or planned satellite missions. For instance, the AXAF program planners were planning to launch in 1991 and perform servicing activities every three years over 15 years. It appeared that the overall cost of demonstrating satellite servicing capability at the Space Station could be reduced by; 1) not duplicating unnecessary simulated servicing prototype equipment and 2) sharing the actual cost of the servicing demonstration mission with the user. In the case of the AXAF mission, which demonstrates retrieval of spacecraft remote from the Space station and also demonstrates capability of using a servicing hangar at the Space station for major satellite repair operations, $22 million of the servicing demonstration is paid by the user, as the spacecraft is built and costs are already invested. The Space Station common costs are shown and include only those cost elements unique to the AXAF servicing missions. Thus, the TDM unique costs are relatively low, including operations support, planning, and some experiment hardware and support equipment. This cost assessment is an example of the expected cost benefit of conducting TDMs, using operational or planned satellites for servicing in the future at Space Station.

1.4 Conclusions - Phase 1

The eight-month Phase 1 study was completed and presented to NASA MSFC in May, 1983. The general conclusions derived from the effort dedicated to the study contract are summarized below:

a. Our servicing task analysis process identified a full spectrum of Space Station satellite servicing mission sets (tasks and related servicing locations) that will require proof-of-concept capability demonstrations at the Space Station. Our supporting cost/benefit analysis suggests the priority for which servicing capability demonstration might be provided. If deployment/assembly of the satellite servicing support area is to be implemented under the auspices of a TDM, it should be the first TDM. In terms of capture of cost beneficial missions, orbit transfer, specifically delivery of payloads to high energy transfer orbits and low energy transfer orbits, would be next. The present state of technology development suggests that the low energy transfer vehicle, OMV, will be available before the high energy upper stage, OTV, even though our cost/benefit analysis which shows that payload delivery to GEO has a higher cost/benefit ratio than delivery to low earth orbit. Earliest deployment of a space-based reusable OMV at Space Station will allow capture of LEO delivery missions, and development of OMV kits will enable capture of LEO satellites and repair or resupply in situ, for retrieval and return to Space Station for repair and resupply. Our analysis supports early development of a space-based, reusable OTV for capture of highly cost beneficial GEO missions, to be performed from Space station rather than STS.

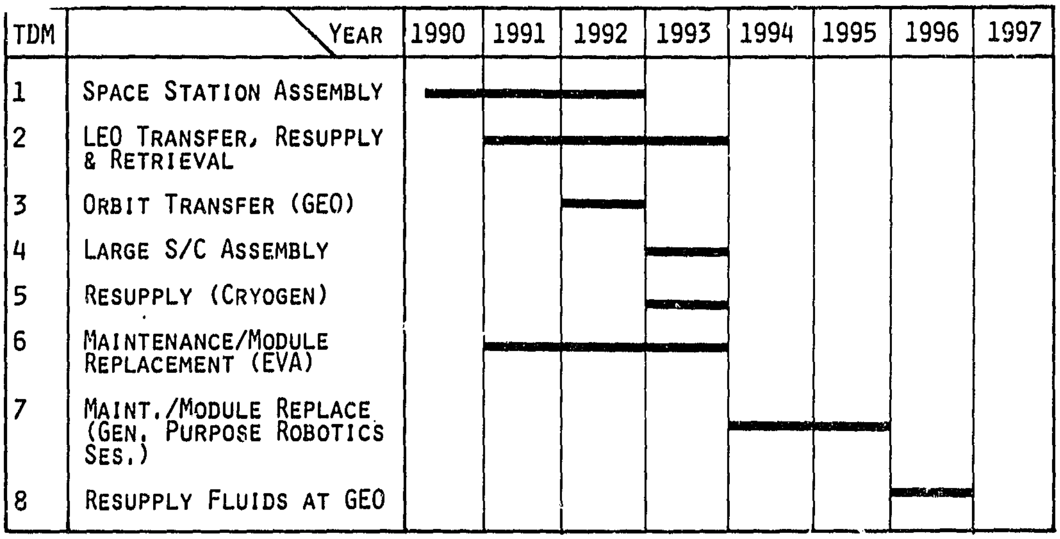

Figure 1.3.6-3 Technology Development Missions Schedule

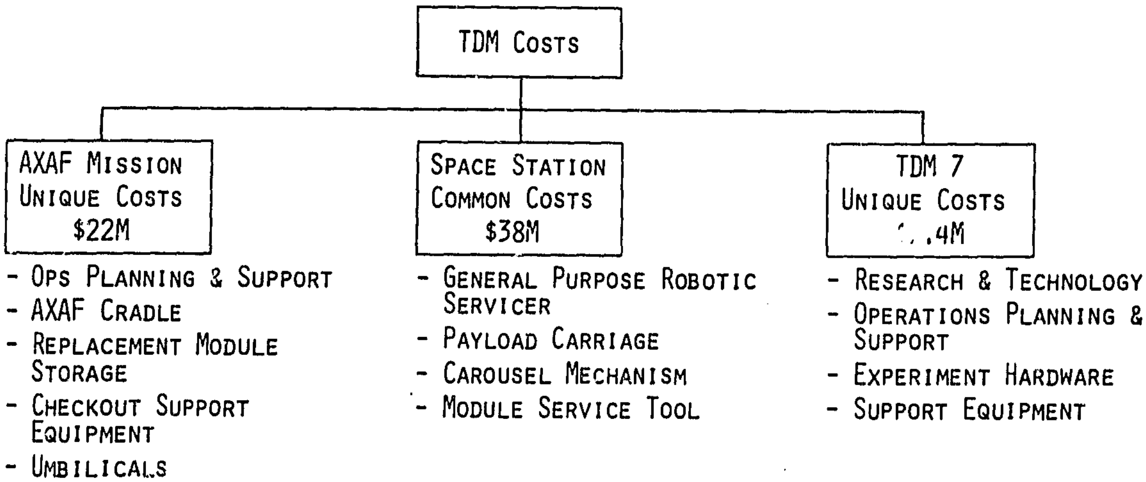

Figure 1.3.6-4 TDM 7 Associated Costs

b. Our selection of eight TDMs demonstrated all of the required Space Station servicing tasks, servicing locations and specialized scenarios identified by the satellite servicing contractors or by NASA/MSFC.

c. The Space Station Mission Model (developed by Martin Marietta for the Phase 1 contract) provided nearly 400 satellite servicing opportunities for the decade of the 1990s, and offers many early IOC satellite servicing candidates for TDM selection.

d. Our assessment of Space station requirements for TDM implementation established a high degree of commonality for Space Station elements, service hangars, storage facilities, berthing and fluid storage/transfer depots and support equipment for all of the eight TDMs. This observation supports ongoing NASA initiatives to continue to develop standard interfaces for Space Station (and STS) servicing operations. Definition and development of standard interfaces and common support equipment for servicing at Space Station will reduce the cost to provide Space Station support equipment, and minimize cost to users. Costs to spacecraft users can be reduced by providing standard interfaces purchased in cost efficient quantities and, where appropriate, provided as government furnished equipment (GFE).

e. This study identified key servicing issues that should be resolved to guide further study activities and to support satellite servicing planning activities.

f. The TDM cost analysis supported the assertion that using operational or planned satellites for servicing demonstrations will reduce the overall cost of demonstrating satellite servicing capabilities at the Space Station.

g. Study results show that the Space Station will provide: 1) an effective and flexible "test bed" for demonstration of servicing capability and procedures at the manned Space Station initially, and 2) capacity for expansion of servicing capability at remote "in situ" locations at both low earth orbits (LEO) and high earth orbits (HEO) including GEO.

2.0 PHASE 2 OVERVIEW

2.1 Purpose of Satellite Servicing Study - Phase 2

The purpose of Phase 2 of the Satellite Servicing Study was to expand and refine the overall understanding of how best to use the manned Space Station as a test bed for demonstration of satellite servicing capabilities. By selecting five specific, high priority Technology Development Missions (TDM), and conducting functional and operational analyses on the TDMs, servicing requirements for Space Station components and support equipment were to be refined and clarified. Specifically, the purpose of Phase 2 was to improve the definition of accommodation requirements necessary to support servicing missions, and to develop an integrated Technology Development and Flight Experiment Plan, to outline a time-phased schedule for ground development and onorbit/validation of technology required for servicing at Space Station. This study was to build on the study results of the initial satellite servicing contract, Phase 1.

2.2 Ground Rules - Phase 2

Ground rules for the Phase 2 study were provided by NASA and are shown below:

a. Use applicable data and results from previous and current studies;

b. Use the STS as the delivery vehicle for servicing elements needed at the Space Station for conduct of TDMs;

c. An early Space Station is to be operational in 1991;

d. The OMV will be available to support onorbit operations;

e. Cost estimates for technology development and TDM implementation is to be supported by ground rules and assumptions;

f. The STS will be available for appropriate early TDM precursor activities.

These ground rules and guidelines were followed in every aspect of Phase 2 study activities.

3.0 STUDY OBJECTIVES - PHASE 2

There were four major study objectives defined for the Phase 2 contract.

The first primary study objective was to define the test bed role of an early (1991-1995) manned Space Station in supporting the technology development required to conduct satellite servicing at the Space Station. Previous studies, including the Phase 1 study, and the Martin Marietta study, Space Station needs attributes and Architectural options, have concluded that substantial cost savings will accrue from performing servicing operations at or from the Space Station. These cost savings will result from: 1) use of space-based reusable low energy (OMV) and high energy (OTV) upper stages at the Space Station for initial delivery of payloads into operational orbits and retrieval of malfunctioning satellites for repair at Space Station (a direct extension of the benefits derived from using the reusable stages of STS); 2) repair or resupply operations at the Space Station (eliminating the need to develop and deliver a new satellite); and 3) conduct of similar repair and resupply operations remote from the Space Station (at low earth and high earth orbits) with reusable OMVs, OTVs and front end service support kits or systems. In addition, a properly configured and accommodated Space Station will provide a servicing capability otherwise not attainable. Presently, scientific platforms and payloads are limited to the size of the STS cargo bay. Space Station will enable both assembly of very large spacecraft and onorbit assembly of large space structures either for experimental or operational use.

The second objective was to select five top priority TDMs and define them in detail. TDM definition was to include functional and operational analyses, leading to derivation of requirements and identification of servicing accommodations.

The third objective was to evaluate the impact of satellite servicing operations on the Space Station, the Space Shuttle and OMV. This objective was primarily intended to ensure that operations involving Space Shuttle and the OMV were documented and interfaces and interactions well detailed.

The last major objective was to attempt to determine the interest of commercial space operators in using the servicing capabilities to be developed on Space Station, and, if possible, assess the potential user's interest in contributing financially to acquisition of these capabilities.

4.0 APPROACH - PHASE 2

The approach used in conducting the Phase 2 satellite servicing study is shown in Figure 4.0-1.

TDM selection was the first step in the study process and was supported by the work accomplished by all four Phase 1 studies, including the large space structures and OTV servicing study. Using all of the TDMs identified by the four contractors, we devised selection criteria and evaluated each of the TDMs to rank order them with regard to value added to servicing at the Space Station. The selected TDMs were reviewed with NASA/MSFC to secure their concurrence.

The detailed definition of selected TDMs was supported by a number of previous STS and Space Station-related studies. Studies and reports on the specific satellites selected for TDM, such as the Advanced X-Ray Astrophysics Facility (AXAF), Electrophoresis Operations in Space (EOS) and the Large Deployable Reflector (LDR), were reviewed and provided excellent support to this study.

Martin Marietta is presently performing a Phase A contract on the OTV, and a Phase B definition contract on OMV. Martin Marietta also designed and developed the Manned Maneuvering Unit (MMU), developed the procedures and provided astronaut training support for an actual planned onorbit satellite servicing/repair mission conducted on the the Solar Maximum satellite earlier this year. These servicing related contracts and programs provided timely support to increasing the realism of TDM definition for the Phase 2 study.

The next sequential study task, using this approach, was to conduct an analysis of Space Station design requirements, to enable design of service support equipment capable of supporting proof of concept servicing demonstrations. The results of this task supported development of the Technology Development and Flight Experiment Plan and the programmatics task of scheduling and costing TDM implementation.

Generation of the Technology Development and Flight Experiment Plan was supported strongly and directly by identification of servicing precursor technology development in Design Requirements Analysis. This precursor technology included basic technology development in several areas such as fluid transfer management, ground controlled, teleoperated docking (for OMV/OTV), aero-assist braking (aerobrake) for OTV, development of techniques and tools for onorbit assembly of adaptive mirror segments, and a wide range of servicing-related automation advances. The Plan also includes onorbit activities both with STS and at the Space Station, needed to provide zero-gravity verification of appropriate technology development advances such as cryogenic fluid transfer management.

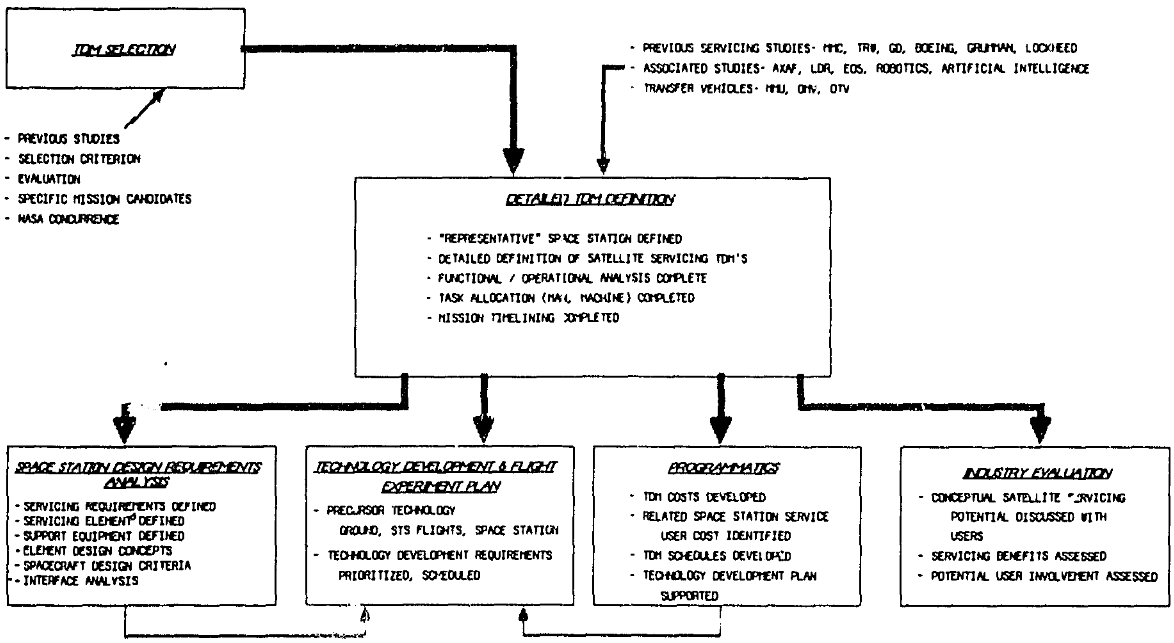

Figure 4.0-1 Satellite Servicing Study Flow

The programmatics portion of the study was directly supported by TDM Definition. The task included development of TDM schedules and TDM costs. Costing ground rules were specified for costing of each TDM. This was essential as the TDMs were significantly different. For each TDM, costs were presented in three categories; 1) Space Station specific costs; 2) user specific costs; and 3) unique costs specifically related to the demonstration activities. One of the conclusions produced by this approach was to demonstrate that TDM costs could be reduced by sharing their costs with prospective users.

The approach used to complete the final task, industry evaluation of satellite servicing at the Space Station, was to call and visit potential commercial users of space to brief them on the anticipated servicing capabilities at the early Space Station, and projection of capabilities at a mature Space Station. These discussions provided insights on plans for commercial operations and insights on planning for servicing both at the STS and subsequently at Space Station. The industrial firms included in this survey provided valuable viewpoints related to the need for specific information to assist them in planning for servicing at or from the Space Station.

5.0 SUMMARY RESULTS - PHASE 2

5.1 TDM Selection Process

The technology development mission selection process used in Phase 2 was straightforward and effective. Subsequent comparisons of these TDMs with evolving Space Station Mission Models have validated the high priorities accorded to the missions. The selection process is summarized on Figure 5.1-1.

The selection criteria are shown in priority rank order. Benefit to users was weighted highest, and number of potential users of the specific servicing task was a consideration for this rating factor. Degree of demonstration potential was also rated high and TDMs demonstrating more than one servicing capability, such as payload delivery and retrieval, and repair and resupply, were accorded higher value in this rating factor than others.

TDM candidates included all those presented by the Phase 1 study contractors; Martin Marietta, TRW, Boeing and General Dynamics Astronautics (GDA). Also included were a number of specific servicing scenarios receiving some element of interest at that point in time, such as "operations at a tethered fuel depot".

These candidate TDMs, 23 in number, were individually evaluated by a number of personnel with extensive Space Station and satellite servicing experience and each TDM rating factor was normalized across all evaluators. The resulting scores were compared and the top five demonstration scenarios were selected. The fifth ranked TDM was a GEO delivery of a satellite with verification of OTV operations included. At the TDM selection/validation meeting held at Martin Marietta Denver Aerospace in October, 1983, MSFC directed replacement of that TDM with an advanced automation servicing capability that would demonstrate the evolution of servicing in a far term mature Space Station.

The selected TDMs are outlined in illustrated form in Figures 5.1-2 and 5.1-3. The highest rated TDM was a mission to resupply a free-flying materials processing platform (MPP) within line-of-sight of the Space Station. The second ranked TDM was a mission designed to retrieve a free-flying satellite from its operational orbit with an OMV, return it to a service hangar at the Space Station, conduct extensive repair and resupply activities on it, and return the satellite to its operational orbit. The AXAF system was selected for this mission because it is ideally configured for these types of servicing tasks, and is currently scheduled for planned maintenance within the period of the early Space Station operations.

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SELECTION CRITERIA

- Benefits to Users
- Degree of Demonstration Potential
- Essentiality
- Risk
- Cost

5 SELECTED TDMS

1. Resupply Materials on Co-Orbiting Material Processing Platform
2. Refurbishment/Maintenance at Space Station Following Retrieval
3. Remote Fully Robotic Maintenance - Advanced Space Station
4. Assembly/Modification of SS Servicing Hangar/RMS Track/RMS
5. On-Orbit Assembly of Large Spacecraft

TDM CANDIDATES

GDA
- Simulated OTV Docking/Berthing
- OTV Maintenance-Engine/Tank Change

Boeing
- Construction/Storage Facility

TRW
- Buildup of Space Station Manipulator System
- On-Orbit Spacecraft Assembly

Martin Marietta
- Space Station Assembly, Modification, Resupply and Maintenance
- Resupply Free Flying Materials Processing Platform
- Geo Delivery, OTV Operations Verification Large Spacecraft Assembly Resupply Cryogens in Leo
- Maintenance/Decontamination
- Module Replacement at SS Retrieve from Leo and Return
- Resupply Fluids at Geo
- Operations at Tethered Fuel Depot

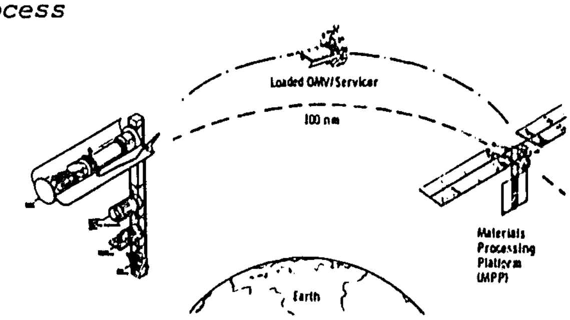
TDM EVALUATION SCORES

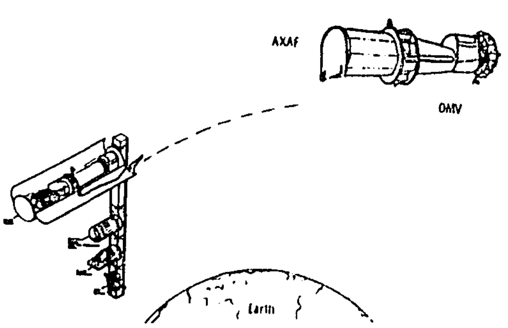
		Benefits to Users	Degree of Demonstration Potential	Essentiality	Risk	Cost	Total
1	Buildup of S/S Manipulator System - TRW	4	4	[illegible]	5	5	25
2	On-Orbit S/C Assembly - TRW	8	[illegible]	8	6	4	35
3	Large Antenna Structure Deploy - TRW	3	3	4		5	22
4	Service/Refurbish Satellite (Geo) - TRW	7	8	8	[illegible]	5	35
5	Service F/F Materials Processing Plat - TRW	[illegible]	9	[illegible]	[illegible]	8	39
6	Simulated OTV Docking/Berthing - GDA	5	3	3	8		24
7	OTV Maint-Engine/Tank Changes - GDA	5	5	3	4	5	22
8	Cryo Propellant Transfer Storage - GDA	5	6	[illegible]	5	5	28
9	OTV/Payload Integration Operations - GDA	6	[illegible]	5	[illegible]	5	30
10	Construction Storage Facility - Boeing	4	3	3	8	4	22
11	Servicing Hanger - Boeing	5	5	5	8	4	27
12	Passive Microwave Radiometer - Boeing	3	6	3	[illegible]	5	24
13	Precision Optical System - Boeing	[illegible]	[illegible]	3	3	3	13
14	S/S Assembly, Mod Resupply & Maint - MMC	7	[illegible]	[illegible]	8	[illegible]	36
15	Resupply Free Flying Materials Processing Platform - MMC	[illegible]	9	8	[illegible]	8	39
16	Geo Delivery, OTV Operations Verification - MMC	9	9	8	5	5	36
17	Large S/C Assembly - MMC	8	[illegible]	8	6	6	35
18	Resupply Cryogens in Leo - MMC	8	[illegible]	8	6	6	35
19	Maint/Decontamination - MMC	[illegible]	6	3	3	5	24
20	Module Replacement at SS, Retrieve from Leo and Return - MMC	8	9	8	[illegible]	5	37
21	Resupply - Fluids at Geo - MMC	6	[illegible]	5	5	5	28
22	Tethered Fuel Depot - MMC/TMS	6	5	7	[illegible]	6	31
23	S/S Platform Refueling - MMC/TMS	3	3	5	8	8	27

Figure 5.1-1 TDM Selection Process

TDM 1—Resupply Free Flying Materials Processing Platform (MPP)

- PREPARE OMV AND MATERIALS PROCESSING MODULE TRANSPORTER FOR ORBIT TRANSFER.
- DELIVER MODULES TO MPP WITH OMV ORBIT TRANSFER.
- RESUPPLY MPP SYSTEMS (MODULE REPLACEMENT).
- RETURN PROCESSED MODULES TO SPACE STATION.
- REFURBISH REUSABLE OMV.





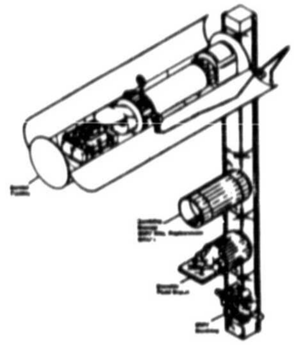
TDM 2—Retrieve/Repair AXAF at Space Station

- RETRIEVE ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF) FROM LOW EARTH ORBIT, FERRY TO SPACE STATION.
- CONDUCT SERVICING OPERATIONS AT SPACE STATION MAINTENANCE FACILITY --
- RETURN AXAF TO OPERATIONAL ORBIT WITH OMV.
- RETURN OMV TO SPACE STATION AND REFURBISH.

Figure 5.1-2 Selected Technology Development Missions

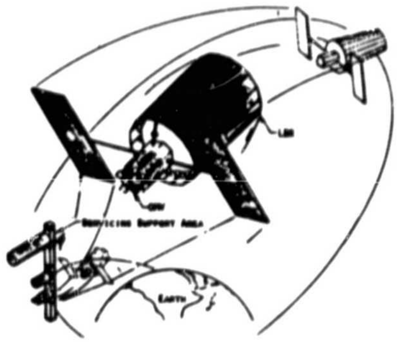
TDM 3—Assembly/Modification of Space Station

- ASSEMBLE RMS TRACK AT EVOLVING SPACE STATION (EVA).
- INSTALL MOBILE SPACE STATION RMS (EVA).
- INSTALL SERVICE STRUCTURE STRONGBACK ELEMENTS (EVA).
- ASSEMBLE SERVICE FACILITY/FUEL DEPOT/STORAGE FACILITY(IES) (EVA).
  - OBJECTIVE: DEMONSTRATE ASSEMBLY/MODIFICATION OF SATELLITE SERVICE ELEMENTS AT SPACE STATION.
  - TDM IS EVOLUTIONARY -- WILL BE ACCOMPLISHED OVER TIME.



TDM 4—On-Orbit Assembly of Large Spacecraft

- RECEIVE/STORE LDR SPACECRAFT ELEMENTS.
- BUILD AND ATTACH STRUCTURAL ELEMENTS.
- CONDUCT ASSEMBLY OF REFLECTOR ELEMENTS.
- DEPLOY LDR TO OPERATIONAL ORBIT WITH OMV.



TDM 5—Remote Repair by Intelligent Servicer

- PREPARE OMV AND INTELLIGENT SERVICER FOR FLIGHT
- DEPLOY SERVICER TO SATELLITE ORBIT WITH OMV.
- SERVICER ANALYZES PROBLEM IN UNSTRUCTURED WORK AREA.
- ANALYSIS FILTERED THROUGH SSMC FOR DECISION, SERVICER ACTION.

Figure 5.1-3 Selected Technology Deveiopment Missions

The third TDM demonstrates one of three servicing categories of interest initially outlined by MSFC during Phase 1 and continued during the Phase 2 contract. The three categories were: 1) Space Station Assembly/Modification; 2) Large Spacecraft Assembly Onorbit; and 3) servicing and repair of satellites at the Space Station. This TDM demonstrates Space Station modification capability. The TDM scenario is assembly of the satellite servicing support area, as this type of mission would add clarity to the definition of specific servicing elements and support equipment required for servicing at Space Station. This objective was clearly achieved.

The objective of TDM 4 was to examine the second major MSFC area of servicing interest, the assembly of large spacecraft in orbit. The number of credible candidates for this mission was very low, and the assembly of the Large Deployable Reflector (LDR) was chosen for two reasons. First, the project was the best defined of those considered, with many related studies available, including some consideration of the assembly problems associated with this mission. Secondly, it is an extremely challenging onorbit assembly sequence, and definition of this assembly process would add clarity to the identification of Space Station accommodation needs.

For the final TDM, MSFC requested Martin Marietta to explore the possibilities offered by space automation to define a servicing scenario for the late 1990s, to demonstrate servicing opportunities potentially available at an evolving mature Space Station. Using the results of an internal independent research and development effort already underway as a starting point, TDM 5 was developed. This technology development mission was designed to illustrate the capability of an advanced technology servicer to conduct nearly autonomous operations, under human "supervisory control", at a disabled satellite in geostationary orbit.

These were the five TDMs approved by NASA MSFC for detailed definition in the Phase 2 portion of the satellite servicing contract.

5.2 TDM Definition

The TDM definition task was interpreted by Martin Marietta to include a thorough description of the mission and the servicing capabilities to be demonstrated by each TDM. The sequence of events for each was outlined to display the results of functional and operational analyses.

The event sequencing included a breakout of pre-mission activities, direct TDM mission activities, and post mission activities. Pre-mission activities were defined as activities directly related to the conduct of the mission, but not labeled as precursor activities. These were subsequently defined. Mission activities were those activities included directly in the actual conduct of the servicing demonstration. Post-mission activities were those activities, following completion of the mission, that would be required to ensure continued orderly Space Station operation such as, cleanup operations, return to earth of TDM residuals, i.e., processed modules, specific TDM equipment, tools, etc.

The TDM event sequencing included a description of activities, crew involvement, support equipment required, event time and elapsed times. For each TDM, servicing requirements derived from the function and operational analyses, were collected as input to the Design Requirements Analysis Task.

In addition, all precursor activities including; 1) basic technology development requirements (technology startups, accelerations); 2) STS flight experiments required to support onorbit or zero-gravity validation of the appropriated technology development; and 3) Space Station validation of equipments and operations concepts for conduct of each of the TDMs, were identified and provided as inputs to the Technology Development and Flight Experiment Plan.

5.2.1 TDM 1 - Resupply of Materials Processing Platform (MPP)

This mission was rated highest primarily because of a belief that interest in commercial operations in space will accelerate with the reality of a near term Space Station. Discussions with McDonnell Douglas Astronautics Corporation (MDAC) planners associated with experimental Electrophoresis Operations in Space (EOS) activities, revealed plans for a number of orbiting platforms requiring frequent resupply of raw materials. The MDAC schedule would have some of these platforms onorbit requiring servicing prior to the advent of initial Space Station operations, making these missions potentially the highest priority missions to attempt to capture. There could readily be a customer fully prepared to pay for the servicing economy inherent in this type of mission.

The Resupply of Free Flying Materials Processing Platform (MPP) mission is outlined in Figure 5.2.1-1. This mission will be described in a greatly compacted format for this executive summary. TDMs 2 and 5 will be expanded to display the level of effort extended to all five TDMs during this phase of the study.

The activities for this mission are summarized in five genetic event sequences. First, all mission events required to prepare an OMV and a replacement module transporter (as a "Transfer Stack") for transport to the remote processing platform were outlined. Next, the mated OMV and front end module transport kit was maneuvered away from the Space Station, using proximity operations maneuvering motors. This action sequence was followed by the OMV transfer operations needed to rendezvous with the MPP and dock the Transfer Stack (OMV and Module Transporter) with the MPP.

Figure 5.2.1-2 illustrates the MPP and docked OMV, and supports description of the highlights of this TDM.

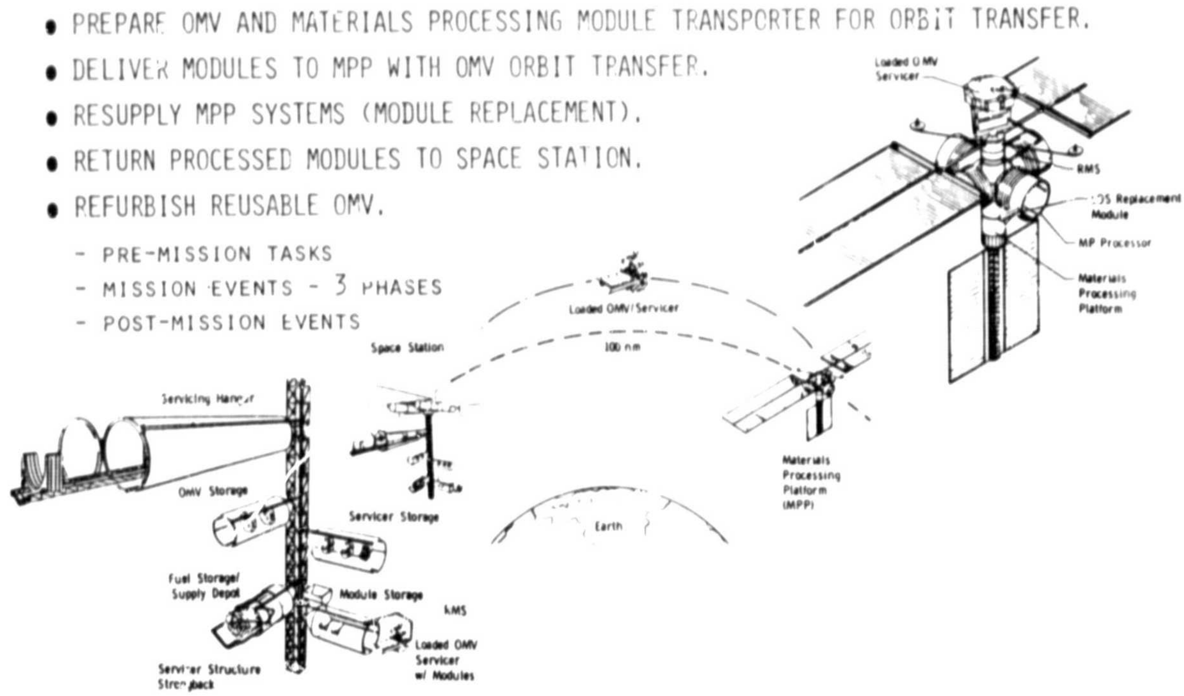


Figure 5.2.1-1 TDM 1 - Resupply Free Flying Materials Processing Platform (MPP)

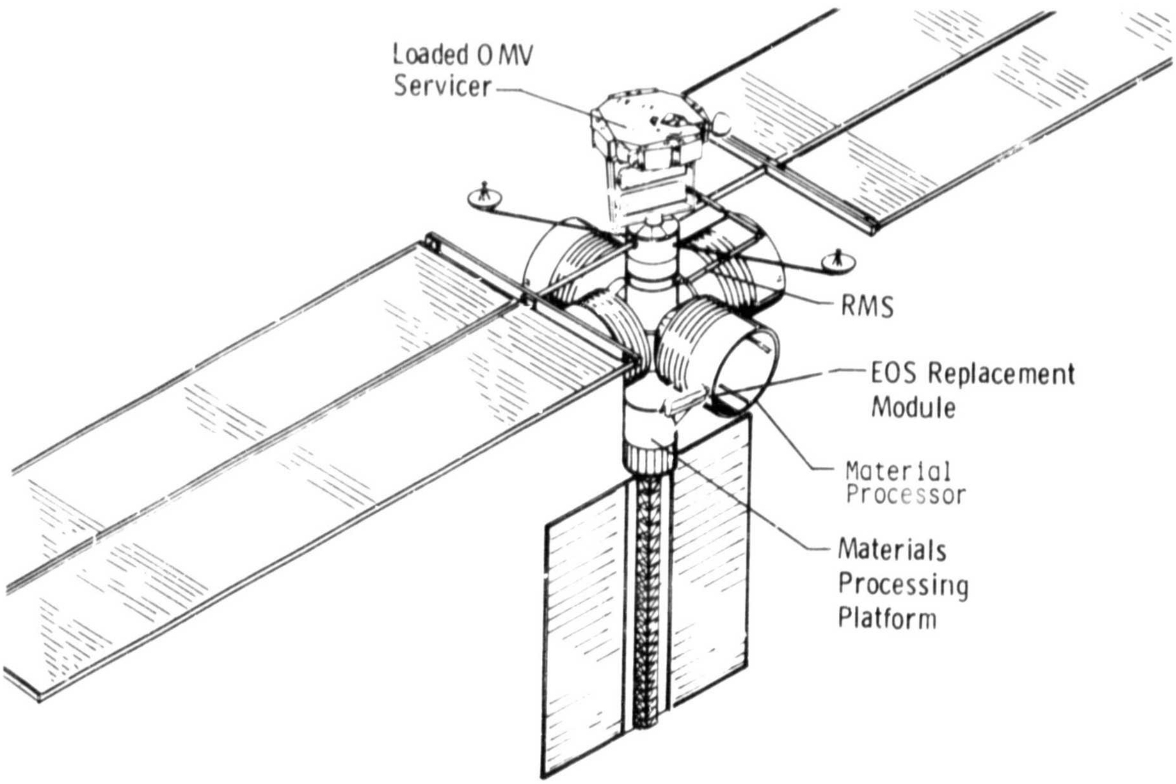


Figure 5.2.1-2 Phase 3 MPP Operations

Shown on the illustration is a postulated free flying platform with four EOS materials processing factories. This platform is configured with a remotely teleoperated manipulator system (RMS), capable of circular translation around the platform, with access to all of the factories for replacement of modules. The MPP RMS is commanded to remove a processed module from one of the EOS processors and stow it temporarily on the platform. The RMS is next teleoperated from Space Station Mission Control (as the MPP is within radio frequency line of sight (RF LOS)), to translate to the OMV/Module Transporter, to extract a new raw material processing unit and install it in the processing system. The same sequence of events is followed to achieve refurbishment of all four materials processing systems.

The remainder of the mission is essentially a reverse of the previous operations, including return of the Transfer Stack to the Space Station, demating and reberthing. There is, of course, one important additional phase of activities. The OMV is a reusable upper stage and must be refurbished, with all essential actions taken to prepare it for a follow-on mission, prior to reberthing it. The same is true for the module transporter.

5.2.2 TDM 2 - Retrieve/Repair AXAF at Space Station

This TDM was rated high initially because of the multiple servicing tasks demonstrated by it. These include satellite retrieval from orbit and return (delivery) to operational orbit, resupply operations at Space Station including module replacement, and instrument bottle/tank replacement (or fluid transfer), and maintenance activities including preventive maintenance in battery replacements and replacement of other equipment expendables, repair of a variety of potential failures, possible refurbishment of antennas and solar arrays (given technology advancements), and finally potential retrofit of new instrument or spacecraft systems. A number of candidates were considered for this mission and the Advanced X-ray Astrophysics Facility (AXAF) was selected because of the extensive level of onorbit servicing already included in the planning for the mission.

TDM 2, AXAF retrieval and repair at Space Station, is illustrated on Figure 5.2.2-1. The major activity sequences as shown are: 1) the retrieval of AXAF from a degraded low earth orbit (205 nautical miles) with OMV; 2) the completion of a large number of potential resupply and maintenance activities conducted on the AXAF while berthed in the Space Station servicing hangar; 3) the return of AXAF to its correct operational orbit; and 4) the return of OMV to Space Station and refurbishment prior to reberthing.

A representative Space Station satellite servicing support area was developed to facilitate description of the servicing activities. This configuration, shown at Figure 5.2.2-2, is different than the configuration shown for TDM 1, primarily because it is a planar configuration with all servicing components situated in one plane aligned along the Space Station velocity vector.

A number of related ground and space-based <u>pre-mission</u> tasks were identified for this task and they are shown on Table 5.2.2-1. These activities include tasks required to prepare for initiation of the TDM. They include getting the required mission specific tools, equipment, and replacement parts to the Space Station, developing and validating procedures and conducting pre-mission training and simulation activities.

An overview of the actual TDM 2 mission activity sequence is shown on Table 5.2.2-2. These activities include OMV preparation for orbit which is primarily checkout of the fueled transfer vehicle and is conducted from an OMV operations panel in Space Station Mission Control (SSMC). The OMV is then transferred to a Space Station deployment point, with an IVA astronaut conducting Space Station RMS (SSRMS) operations. The OMV console operator transfers OMV from Space Station to a safe launch initiation position, using inert gas to minimize contamination from main engine(s) fuel residuals.

Control of OMV is then transferred to SSGC (ground control) and the OMV launch is initiated to place OMV in close proximity to AXAF. The rendezvous with AXAF is accomplished by: 1) on-board collection of OMV position data from Global Positioning System (GPS), 2) on-board collection of AXAF position data from ground tracking through TDRSS, and use of new guidance, navigation and control (GN&C) algorithms to affect the rendezvous. Docking with AXAF is then accomplished using ground-controlled teleoperation.

SSGC next returns the mated OMV/AXAF to the Space Station, and through a directly reverse process, OMV is returned to the service hangar for refurbishment in preparation for reinserting AXAF to a new operational orbit. AXAF is then transferred, using SSRMS, to the service hangar, and readied for service operations.

As shown on Table 5.2.2-2, these refurbishment or repair operations could require anywhere from one or two days, to as many as eight to ten, depending on how much resupply and refurbishment repair is required on the first planned AXAF mission. Also shown, is the overview of the timeline of the remainder of the AXAF mission. The actual TDM mission timeline reflects a total of approximately 10 hours, and whatever time the repair mission actually requires.

- RETRIEVE ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF) FROM LOW EARTH ORBIT. FERRY TO SPACE STATION.
- CONDUCT SERVICING OPERATIONS AT SPACE STATION MAINTENANCE FACILITY --
  - REPLACE SCIENCE INSTRUMENT ORUs (9 MAXIMUM)
  - REPLACE DEPLETED INSTRUMENT GAS BOTTLES WITH CHARGED BOTTLES (5 BOTTLES)
  - REPLACE SPACECRAFT SUBSYSTEM ORUs (16 MAXIMUM)
- RETURN AXAF TO OPERATIONAL ORBIT WITH OMV.
- RETURN OMV TO SPACE STATION AND REFURBISH.

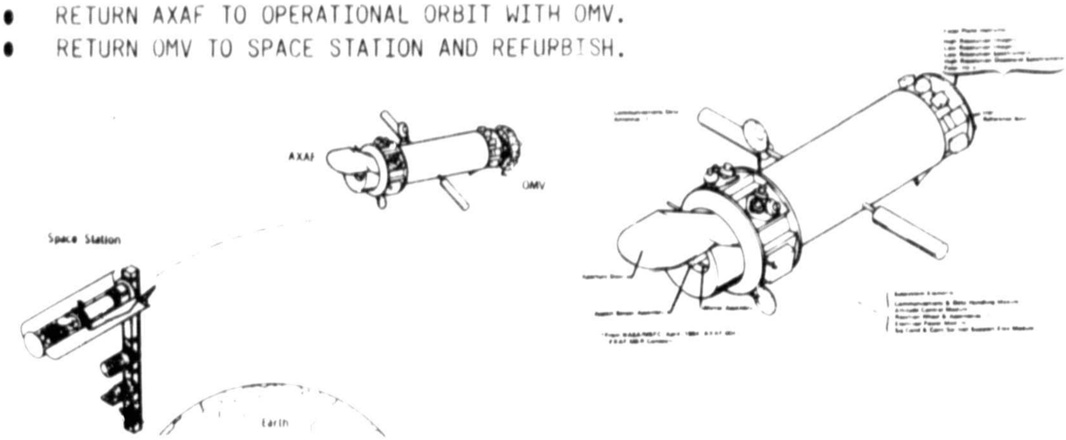


Figure 5.2.2-1 TDM 2 - Retrieve/Repair AXAF at Space Station

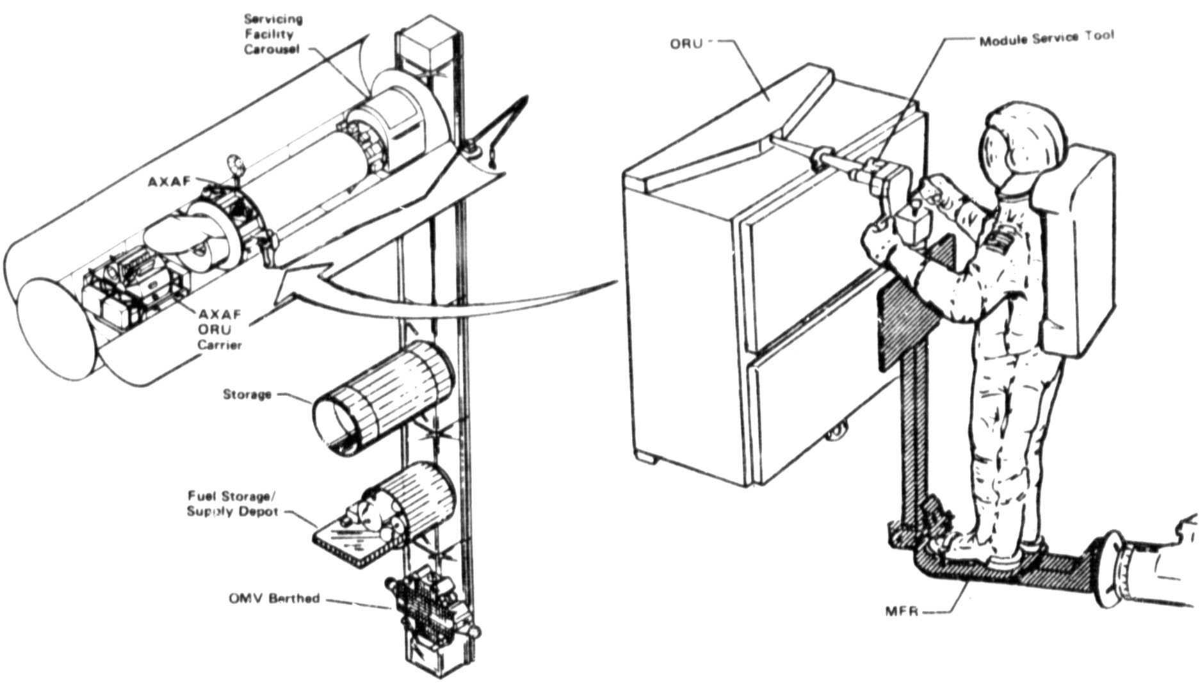


Figure 5.2.2-2 AXAF Repair/Resupply

Table 5.2.2-1 Related Pre-Mission Tasks

GROUND BASED:

- IDENTIFY REQUIRED SUPPORT EQUIPMENT, TOOLS -- DESIGN, TEST, AND DELIVER TO SPACE STATION.
- DELIVER RESUPPLY MODULES, GAS BOTTLES, BATTERIES, ETC, TO SPACE STATION.
- DEVELOP AND VALIDATE OPERATIONAL PROCEDURES/CONDUCT TRAINING.
- PLAN/COORDINATE TDM ACTIVITIES/TIMELINES, COORDINATE WITH AXAF MISSION CONTROL.

SPACE STATION:

- RECEIVE, TEST AND STORE REPAIR EQUIPMENT, TOOLS FOR REPAIR MISSION.
- RECEIVE, STORE AXAF RESUPPLY MODULES, GAS BOTTLES, BATTERIES.
- ASSIST IN DEVELOPING OPERATIONAL PROCEDURES, CONDUCT TRAINING AND PERFORM REALISTIC SIMULATION ACTIVITIES.

Table 5.2.2-2 AXAF Retrieve/Repair Mission Timeline

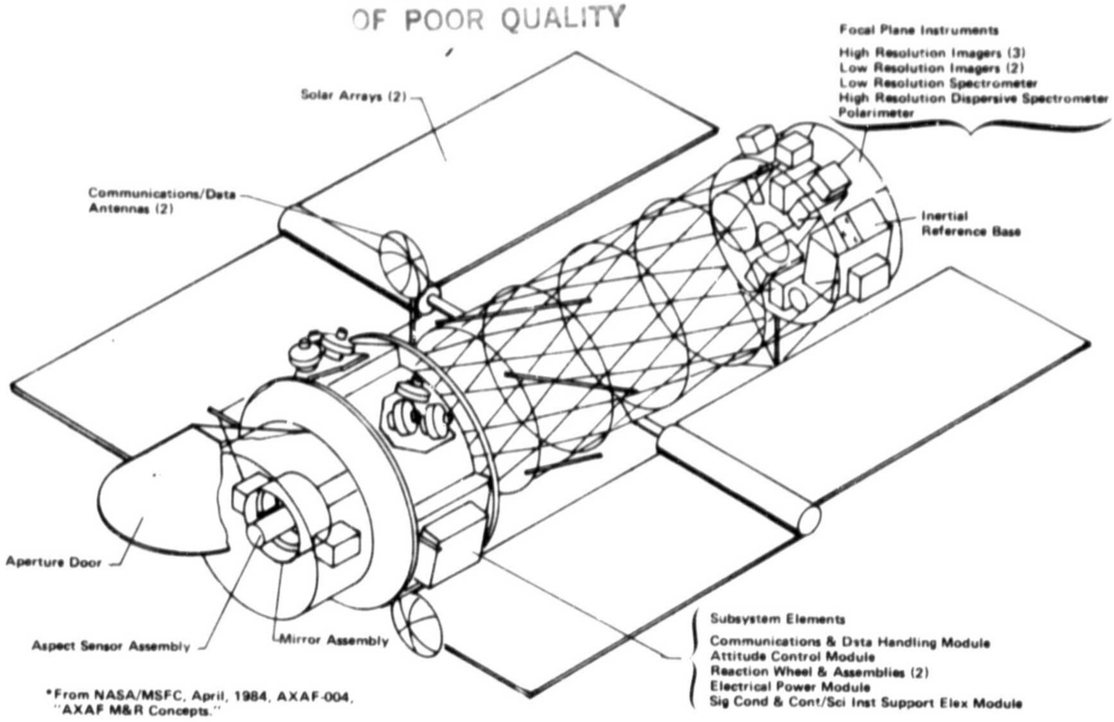
MISSION SEQUENCE	SEQUENCE TIME (HOURS)	MISSION ELAPSED TIME (HOURS)
CHECKOUT OMV FOR AXAF RETRIEVAL	0.5	0.5
TRANSFER OMV TO STANDOFF LAUNCH POSITION	0.3	0.8
OMV ORBIT TRANSFER/RENDEZVOUS WITH AXAF	1.0	1.8
OMV DOCK WITH AXAF	0.1	1.9
OMV/AXAF ORBIT TRANSFER/RENDEZVOUS WITH SPACE STATION	1.0	2.9
AXAF BERTHED TO SPACE STATION SERVICING CAROUSEL	0.5	3.4
OMV BERTHED TO SPACE STATION	0.3	(PARALLEL ACTIVITY)
	0.3	(PARALLEL ACTIVITY)
OMV REFUELED, REFURBISHED, STORED	3.2	(PARALLEL ACTIVITY)
AXAF REPAIRED/REFURBISHED, REPLENISHED (EVA)	1-10 DAYS	---
CHECKOUT OMV FOR AXAF RETURN	0.5	3.9 + AXAF REPAIR
OMV MATED WITH AXAF	0.3	4.2 + AXAF REPAIR
OMV/AXAF TRANSFER TO STANDOFF LAUNCH POSITION	0.3	4.5 + AXAF REPAIR
OMV/AXAF TRANSFER TO AXAF OPERATIONAL ORBIT	0.8	5.3 + AXAF REPAIR
AXAF SEPARATED FROM OMV	0.2	5.5 + AXAF REPAIR
OMV ORBIT TRANSFER/RENDEZVOUS WITH SPACE STATION	1.0	6.5 + AXAF REPAIR
OMV BERTHED TO SPACE STATION	0.3	6.8 + AXAF REPAIR
OMV REFUELED, REFURBISHED, RESTORED	3.2	10.0 + AXAF REPAIR
MISSION COMPLETE		10.0 + AXAF REPAIR

Throughout the 18 month period of performance of this study contract, Martin Marietta communicated frequently with the AXAF program office, particularly with a group associated with servicing plans for AXAF. An AXAF servicing document entitled, "AXAF Maintenance and Repair Concepts", NASA/MSFC, AXAF-004, April, 1984, provided excellent support to the TDM 2 definition task. As shown in Figure 5.2.2-3, the AXAF satellite, including spacecraft/scientific instrument elements, is configured extensively for servicing. AXAF planners are currently considering five servicing missions over a 15 year period of operations, including final retrieval and return to earth. The spacecraft and scientific systems have been designed with addressibility to essentially every system component. Table 5.2.2-3 highlights the level of servicing activities being considered by AXAF planners. Spacecraft subsystems to be configured for onorbit replacement total 18 in number, including systems such as the solar arrays and the aspect sensor assembly. Replacement of the aspect sensor assembly will be a challenging servicing task, principally because of sensor handling activities requiring realignment of the mirror assembly and the necessity for stringent contamination control during operations. In addition, servicing planners have considered 23 science instrument subsystems for onorbit replacement, and are considering development of orbital replacement units (ORUs) for each of these.

Thus, an estimation of specific AXAF servicing time for the first AXAF mission is premature at this time. However, a series of eight EVA activity days were detailed to investigate the operational aspects of this servicing demonstration mission and to refine estimates of Space Station requirements and accommodations. An example of this analysis is shown in Table 5.2.2-4. This is the second planned EVA day, and this day is dedicated to removal of faulty scientific instrument ORUs, (recall that AXAF is configured for replacement of 23 of these subsystem elements). The operational timeline includes EVA preparation, transit to the service hangar and ORU replacement time. Estimates were based on experience gained on Solar Maximum ORU replacement.

Upon completion of AXAF servicing, return to orbit, and return of OMV to Space Station for refurbishment and reberthing, the actual TDM activity is complete.

AXAF post mission tasks are limited in scope. The mission specific equipment including an AXAF ORU carrier, a rotating carousel containing all AXAF ORUs situated temporarily in the service facility for convenient presentation of ORUs to the astronauts (see Figure 5.2.2-2), must be returned to earth to avoid unnecessary accumulation at Space Station. Also, OMV fuels and pressurant levels must be retained at proper levels, so these may require replenishment. Finally, this mission is a multi-service oriented mission, with a large number of "lessons learned" anticipated. The equipment and operations used in the mission will be thoroughly reviewed to refine related follow-on missions.



*From NASA/MSFC, April, 1984, AXAF-004, "AXAF M&R Concepts."

Figure 5.2.2-3 Current AXAF ORU Baseline

Table 5.2.2-3 AXAF ORU Equipment Complement

SCIENCE INSTRUMENTS	ORU'S	ELECTRONIC MODULES	GAS SUPPLY ORU'S
MRI- MODERATE RESOLUTION IMAGER	2	2	2
HRDS- HIGH RESOLUTION DISPERSIVE SPECTROMETER	1	1	2
MRS- MODERATE RESOLUTION SPECTROMETER	1	1	-
FPP- FOCAL PLANE POLARIMETER	1	1	1
HRI- HIGH RESOLUTION IMAGER	3	3	-
MPC- MONITOR PROPORTIONAL COUNTER	1	1	-
TOTAL	9	9	5

SPACECRAFT SUBSYSTEMS	ORU'S
SCCU/SISE- SIGNAL CONDITIONING AND CONTROL UNIT/ SCIENCE INSTRUMENT SUPPORT ELECTRONICS	1
ACS- ATTITUDE CONTROL SYSTEM	1
C&DH- COMMUNICATIONS AND DATA HANDLING	1
EPS- ELECTRICAL POWER SYSTEM	1
REACTION WHEEL	2
INERTIAL REFERENCE BASE	1
SOLAR ARRAYS	2
MAGNETIC TORQUER	6
ASPECT SENSOR	1
ANTENNAS	2
TOTAL	18

TOTAL NUMBER OF REPLACEABLE MODULES 41

During detailed definition of TDM 2, a number of "precursor" activities were identified. Precursor activities are defined as those technology development and requisite onorbit technology verification enterprises that must be undertaken or completed to enable conduct of the TDM. For the AXAF retrieval/repair mission, those precursor activities are shown in Table 5.2.2-5. A space-based reusable OMV must be developed, tested repeatedly in various STS flight experiments, and validated for operations at Space Station, utilizing the accommodations provided at Space Station to support OMV operations. OMV onorbit operations are dependent on resolution of fluid transfer management issues, including onorbit fluid transfer, mass gauging, leak proof quick disconnects, and onorbit storage of both storable and cryogenics.

Another precursor technology activity that must be initiated on the ground, and then space validated, is the design and development of the Space Station service support area. Though perhaps an obvious precursor activity, it is included to ensure full precursor description.

For AXAF, the design and development of the ORU carrier must be completed to enable conduct of this TDM. Every effort should be made to ensure use of standard tools being developed for similar missions, such as for Space Telescope on the STS.

STS Flight Experiments are a second category of TDM precursor activities. Those new technology starts requiring onorbit validation, such as fluid transfer, can be accommodated efficiently by STS flight experiments. Demonstrations of onorbit refueling of OMV will be performed using the STS. Demonstrations of fuel transfer from Space Station fuel storage depots are logical STS flight experiment candidates. Docking and berthing of the OMV, mating of the OMV and free-flying satellites, and OMV/Space Station proximity operations are additional flight experiment initiatives.

Space Station validation of satellite servicing support elements and equipment will also be required prior to initiation of the AXAF resupply/repair TDM. The servicing support equipment; i.e., service hangar, OMV berth, storage hangars/facilities and fluid depots must be installed and appropriately tested/exercised. Special AXAF support equipment must be delivered to Space Station and verified using exercise scenarios.

A final phase of precursor activities at the Space Station is a recommended simulation of the actual AXAF repair mission. Solar Maximum repair mission "lessons learned", suggests the modification of a SPAS-type pallet to create a high-fidelity mockup of AXAF. This mockup would require AXAF/OMV, AXAF service hangar and AXAF/ORU interfaces to enable Space Station proximity operations testing. The OMV would deploy to retrieve the mockup and return it to the service facility. Servicing simulation activities, including ORU replacement and antenna or solar array replacement/refurbishment, would then be conducted on the AXAF mockup in the service hangar.

Table 5.2.2-4 AXAF Module Replacement Operational Timeline

EVENT	CREW	CONTROL MAN	CONTROL AUTO	EVENT TIME	ELAPSED TIME	SUPPORT EQUIPMENT
MOVE 2 EVA ASTRONAUTS FROM AIRLOCK TO SERVICING FACILITY	2 EVA, 1 IVA	100		35 MIN	0+35	SS RMS CONTROL/ SS RMS
PREPARE TO SERVICE AXAF						
o GET PROPER TOOLS		100		10 MIN	0+35	
o MOUNT MFR TO SERVICING FACILITY RMS		100		10 MIN	0+35	SERVICING RMS
o EVA #1 MOUNTS MFR AND MOVES TO SCIENCE INSTRUMENT HOUSING ON AXAF	2 EVA, 1 IVA	100		10 MIN	0+45	SERVICING RMS
SERVICE SCIENCE INSTRUMENTS						
o OPEN AFT HINGED DOOR OF AXAF	2 EVA, 1 IVA	100		15 MIN	1+00	SERVICING RMS MODULE SERVICE TOOL
o DISCONNECT MRS MODULE	1 EVA, 1 IVA	100		15 MIN	1+15	SERVICING RMS MODULE SERVICE TOOL
o EVA #2 REMOVES REPLACEMENT MRS MODULE FROM RESUPPLY CAROUSEL	1 EVA	100		10 MIN	1+15	
o EVA #1 REMOVES EXPENDED MRS MODULE FROM AXAF	2 EVA, 1 IVA	100		5 MIN	1+20	SERVICING RMS MODULE SERVICE TOOL
o MOVE EXPENDED MRS TO RESUPPLY CAROUSEL	2 EVA, 1 IVA	100		10 MIN	1+30	SERVICING RMS
o EVA #2 PLACES EXPENDED MRS MODULE IN RESUPPLY CAROUSEL	1 EVA, 1 IVA	100		10 MIN	1+40	MODULE RESUPPLY CAROUSEL
o EVA #1 RETURNS TO AFT END OF AXAF WITH REPLACEMENT MRS MODULE	1 EVA	100		10 MIN	1+40	SERVICING RMS
o EVA #1 REPLACES AND CONNECTS REPLACEMENT MRS MODULE IN AXAF	2 EVA, 1 IVA	100		20 MIN	2+00	SERVICING RMS MODULE SERVICE TOOL
o EVA #1 DISCONNECTS HRDS MODULE	1 EVA, 1 IVA	100		15 MIN	2+15	SERVICING RMS MODULE SERVICE TOOL
o EVA #2 ROTATES RESUPPLY CAROUSEL	1 EVA	100		5 MIN	2+15	MODULE RESUPPLY CAROUSEL
o EVA #2 REMOVES REPLACEMENT HRDS MODULE FROM RESUPPLY CAROUSEL	1 EVA	100		10 MIN	2+15	MODULE RESUPPLY CAROUSEL
o EVA #1 REMOVES EXPENDED HRDS MODULE FROM AXAF	2 EVA, 1 IVA	100		5 MIN	2+20	SERVICING RMS MODULE SERVICE TOOL
o MOVE EXPENDED HRDS TO RESUPPLY CAROUSEL	2 EVA, 1 IVA	100		10 MIN	2+30	SERVICING RMS MODULE SERVICE TOOL
o EVA #2 PLACES EXPENDED HRDS MODULE IN RESUPPLY CAROUSEL	1 EVA, 1 IVA	100		10 MIN	2+40	MODULE RESUPPLY CAROUSEL
o EVA #1 RETURNS TO AFT END OF AXAF WITH REPLACEMENT HRDS MODULE	1 EVA	100		10 MIN	2+40	SERVICING RMS
o EVA #1 REPLACES AND CONNECTS REPLACEMENT HRDS MODULE IN AXAF	2 EVA, 1 IVA	100		20 MIN	3+00	SERVICING RMS MODULE SERVICE TOOL
o REPEAT FOR EACH FAULTY/ SCHEDULED REPLACEMENT INSTRUMENT	2 EVA, 1 IVA	100		AS RQD	AS RQD	
RETURN 2 EVA ASTRONAUTS TO AIRLOCK	2 EVA, 1 IVA	100		35 MIN	6+00	SS RMS CONTROL, SS RMS

Table 5.2.2-5 Precursor Activities - Preliminary

- GROUND
  - OMV-SAME AS MPP TDM, FUEL TRANSFER MANAGEMENT, STORAGE
  - SPACE STATION SUPPORT AREA VALIDATION-SAME AS MPP TDM
    - SERVICE HANGAR, FUEL DEPOT, OMV BERTH, STORAGE AREA

  AXAF
  - ORU CARRIER-DESIGN, DEVELOPMENT, TEST
  - SPECIFIC TOOLS-DESIGN, DEVELOPMENT, TEST-(MAY BE NONE)

- STS FLIGHT EXPERIMENTS/TESTS
  - OMV-PREVIOUSLY DESCRIBED
  - SERVICING SUPPORT AREA-FUEL TRANSFER/STORAGE TESTS-LOW LEVEL
  - AXAF
    - ORU CARRIER-ON ORBIT VALIDATION, OPERATIONAL PROCEDURES
    - SPECIFIC TOOLS-TEST

- SPACE STATION VALIDATION
  - OMV-RETRIEVAL OF MOCK AXAF SPACECRAFT
  - DEPLOYMENT OF ORU CARRIER-VALIDATION EXERCISES
  - DEPLOYMENT OF SERVICING SUPPORT AREA (TDM 3), VALIDATION OF SERVICING EQUIPMENT/OPERATIONAL SUPPORT

These precursor activities represent a top level evaluation of the types of technology development and flight experiments required to prepare for the AXAF servicing demonstration mission, and this data served as an input to the Technology Development and Flight Experiment Plan.

A final step in the definition of TDM 2 was the development of a Technology/TDM Implementation Plan for the mission. Shown at Figure 5.2.2-4 is a time-phased program for development of the technology required to conduct the TDM, and the schedule of activities required for either NASA or a TDM contractor to implement the TDM. The figure highlights AXAF, OMV and Space Station program milestones, and presents the sequence of AXAF maintenance and repair activities; i.e., ground developments, STS and Space Station validations that will be conducted to prepare to conduct TDM 2. Also shown on the bottom of Figure 5.2.2-4 are the TDM implementation operations leading up to the demonstration mission, tentatively set for 1994.

5.2.3 TDM 3 - Satellite Servicing Support Area Assembly

This TDM demonstrates the servicing capability of Space Station modification. As previously stated, the servicing demonstration is one of the three NASA identified areas of general servicing interest. The specific task was modifying the Space Station by adding the satellite servicing support area to an assembled Space Station. The servicing elements added were; a satellite servicing hangar (cylindrically shaped, 30 feet by 70 feet), a storage facility (similar shape and scaled down to 15 feet by 30 to 50 feet), a fluid storage/transfer depot and a berthing station for OMV.

The mission was designed to enable transport of all assembly elements to the Space Station in two STS flights. On the first flight, all materials for a service strongback support structure, the service hangar and the OMV berthing mechanism were loaded in two STS cargo canisters, transferred to Space Station and deployed with the SSRMS to berthing ports in close proximity to the assembly location. The cargo canisters were included to allow rapid removal of the assembly materials from STS, to free it for return to earth, and to enable temporary storage of the assembly materials. The assembly is projected to require a significant amount of time and the container thus resolves storage problems for both the STS and the Space Station. This container is also used in TDM 4, and could be used in many TDM scenarios to return residuals to earth when the mission is completed.

Phase 1 of the Service Support Area Assembly is shown in Figure 5.2.3-1. The first deployable service strongback support element is shown being removed from the first cargo canister by a dual-armed, remotely operated SSRMS. The SSRMS is already installed on a tracked system that enables the SSRMS full access to the Space Station. The support element is then deployed by RMS teleoperation and attached to

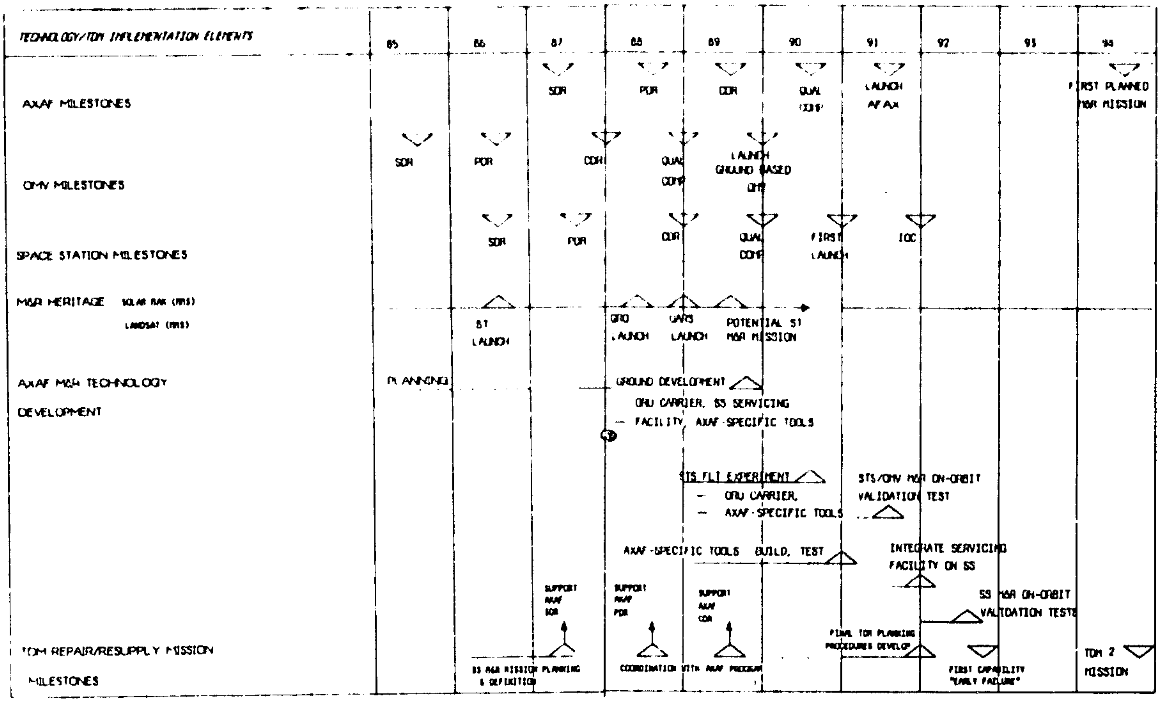


Figure 5.2.2-4 Technology Development Phasing

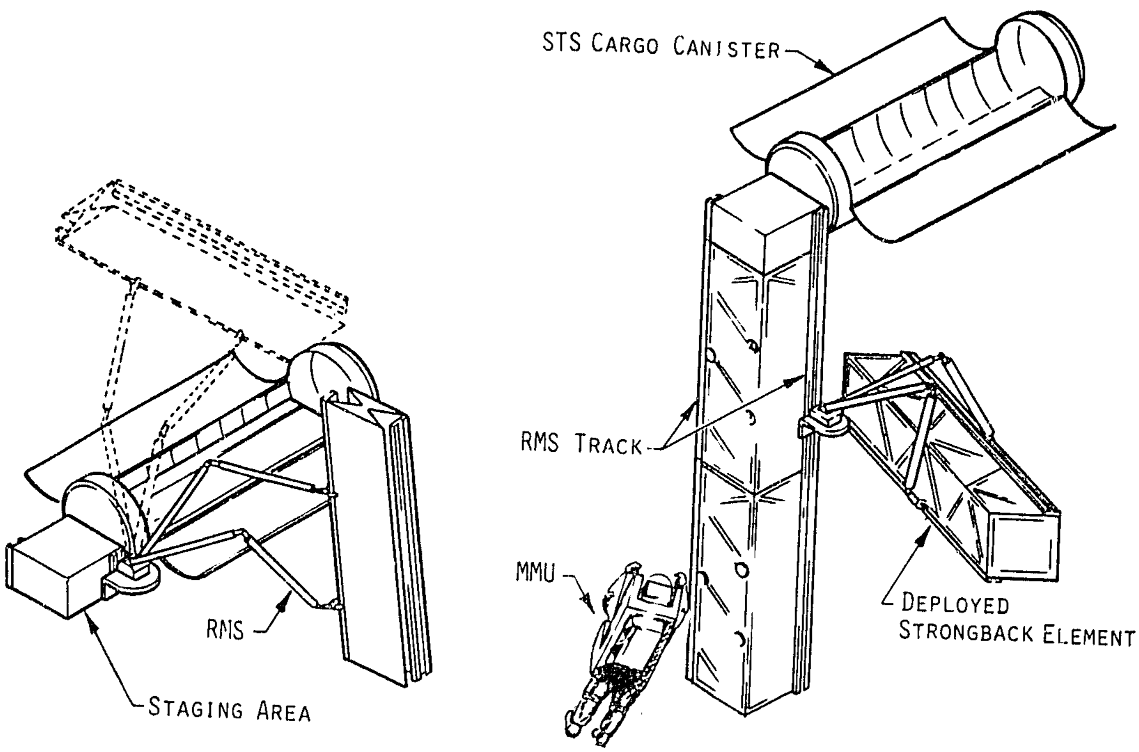


Figure 5.2.3-1 Support Area Assembly

the nucleus of the Space Station. The automatic alignment, mating and latching process is closely monitored by astronauts in close proximity, and manual assist will be provided as appropriate. These elements are 30 feet long and five sections are connected to form a 150 feet long support structure.

The next element assembled in this mission is the service hangar. Assembly of the service hangar is represented on Figure 5.2.3-2. The second cargo canister is shown loaded with service hangar assembly elements and these elements are removed and transferred to the hangar assembly area. The assembly operations are conducted with he coordinated efforts of the SSMC (mission control) RMS operator operating the dual arm, tracked manipulator, and supported by astronauts in EVA. The astronauts will use the MMU until relocatable foot restraint supports are available, and will then use foot restraints for improved assembly support capability, sans MMU. A rotatable spacecraft berthing mechanism is attached first to the strongback. Then, payload bay like cradle racks are attached, along with SSRMS track to provide RMS accessibility to the assembly operation. Following installation of the satellite servicing support equipment, including umbilicals, storage racks, and translatable astronaut work stations, a circular shielding material is assembled to provide micrometeoroid, thermal and radiation shielding for satellites to be serviced in the hangar.

The third phase of this Space Station modification TDM is illustrated on Figure 5.2.3-3. The shielded service hangar and OMV berthing ring are shown attached to the service strongback support structure. The STS is represented as docked at Space Station with the second cargo load for this TDM. The dual-armed SSRMS has grappled the servicing storage facility, (assembled on earth as it is sized to be cargo bay compatible), and will transfer it to an assembly point on the service support structure. The storage hangar will be aligned for mating by the SSRMS operator, and latched and checked by supporting astronauts in EVA. The fuel depot, also shown in the STS, will be transferred similarly to an assembly point just above the OMV berthing ring, and securely attached to the strongback support area.

Following attachment of each service element to the strongback, the interface connections between elements and the strongback will be made. Power, data handling, and fluid transfer connects will be made by astronauts to provide required Space Station support to each of the servicing elements.

This completes a top level representation of the TDM 3 activities. The completed satellite servicing support area is shown at Figure 5.2.3-4.

There were a number of major issues generated by the definition and detailed description of this assembly TDM. First, top level trade studies should be initiated to determine how the service strongback should be configured, either deployable, executable or some hybrid method. Secondly, it is recognized that a relocatable, or translatable RMS will be required for servicing at the Space Station. Trade studies are ongoing regarding optimal solutions to providing this capability. A third issue relates to what degree, if any, of shielding will be

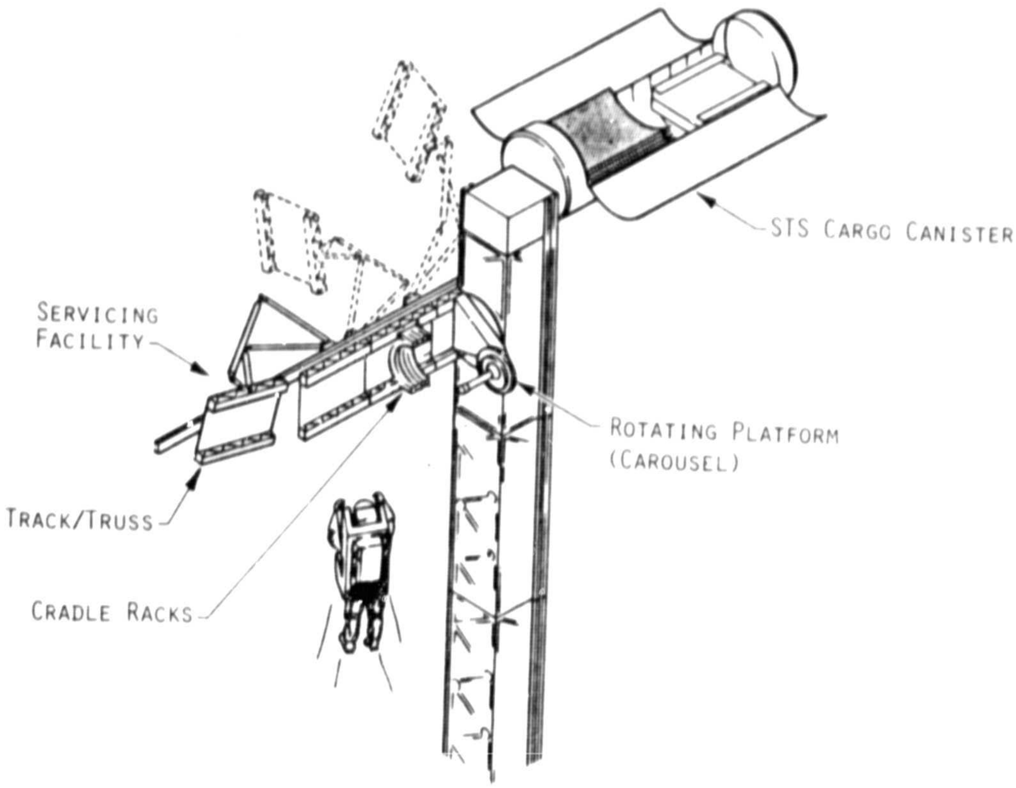


Figure 5.2.3-2 Service Support Area Assembly - Phase 2

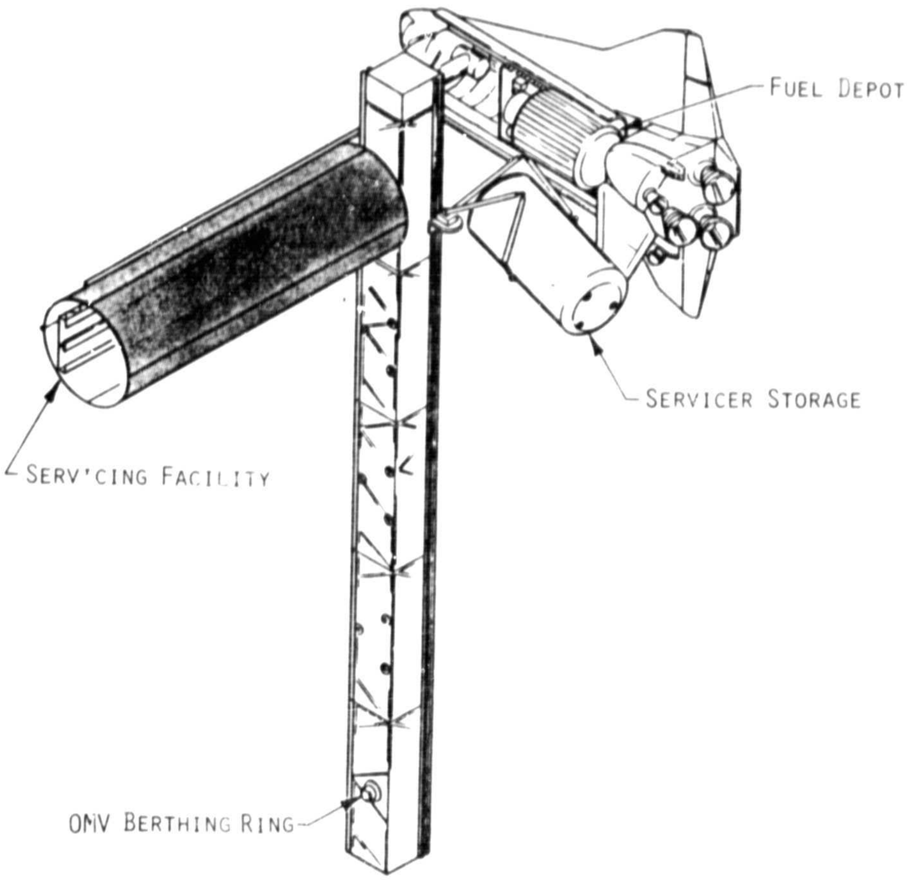


Figure 5.2.3-3 Service Support Area Assembly - Phase 3

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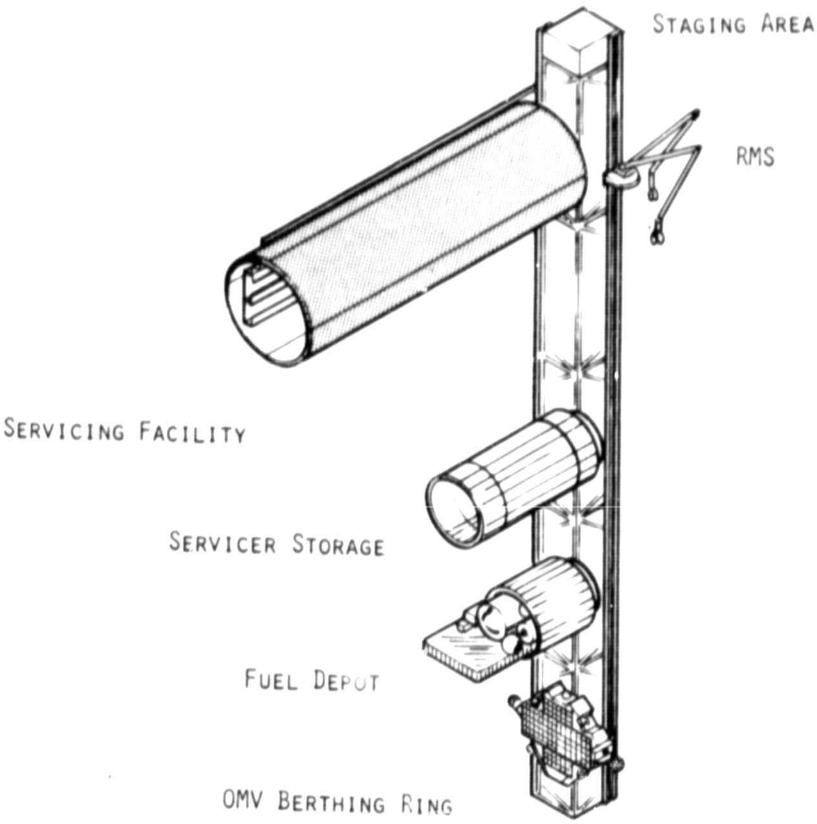

Figure 5.2.3-4 Service Support Area Assembly - Phase 3

required for servicing elements. Another major issue surrounds the question of how man can best be used, and best supported in conducting assembly operations at Space Station. The assembly operations envisioned for this mission indicate a substantial amount of required EVA time. "In EVA operations"; according to Owen Garriot (communicated in an Advanced Automation Panel conference at California Space Institute in July, 1984), "man is about 10% as capable as he is in a shirt sleeve environment". This supports the position taken in this study that advanced, automated manipulator systems will be required to support servicing operations at Space Station and increase the effectiveness of man in this environment. The resolution of these significant assembly support issues was beyond the scope of this contract.

5.2.4 TDM 4 - Assembly of Large Spacecraft

The Large Spacecraft Assembly mission addressed the second principal servicing category identified for Phase 2 of the Satellite Servicing study. Onorbit assembly of large spacecraft at the manned Space Station will add a new dimension to considerations for scientific and commercial use of space. Several current large spacecraft concepts, presently in various stages of planning, were considered as candidates for this mission. The Large Deployable Reflector (LDR) appeared to be the best defined future mission of this type and was selected for that reason. The onorbit assembly of LDR also appeared to offer significant technology challenges and would add additional breadth and depth to definition of Space Station servicing requirements and accommodation needs.

The general outline of this TDM is illustrated on Figure 5.2.4-1. The detailed definition of the mission was outlined in four top level activity phases. The first activity grouping includes those mission events related to delivery of the LDR spacecraft/scientific instrument, the structural and reflector elements of the mirror assembly. Current planning estimates indicate that all LDR assembly components can be delivered to the Space Station in two Shuttle orbiter missions.

The second phase involves assembly of the 20 meter (diameter) mirror assembly on the Space Station, and attachment of a 20 meter long sunshade to the mirror, using the SSRMS and an RMS-mounted servicing work station (to support EVA) to conduct the assembly. The final two stages include deployment of the assembled LDR to its operational orbit using OMV, and the final task of returning OMV to the Space Station for refurbishment and reberthing.

The first phase of TDM 4 is illustrated on Figure 5.2.4-2, and two major activity sequences are highlighted. The LDR spacecraft and scientific instrument package are mated in the STS cargo bay, using the STS RMSs. The two spacecraft are not mated in the cargo bay on the ground and then transported in a mated configuration, as the cantilever support mechanism required to enable this would add unnecessary payload weight. The second activity sequence shown is the transport of the mated LDR spacecraft/scientific instrument package, using SSRMS, to the service strongback support. This assembly package is attached to a previously installed rotating berthing ring. This rotating ring will support mirror assembly operations.

- DELIVER LARGE DEPLOYABLE REFLECTOR (LDR) STRUCTURAL ELEMENTS AND REFLECTOR SEGMENTS TO SPACE STATION IN TWO ORBITER MISSIONS.
- ASSEMBLE LDR ON SERVICE STRUCTURE STRONGBACK USING MMU AND STATION RMS/WORK PLATFORM.
- DEPLOY LDR TO OPERATIONAL ORBIT WITH OMV.
- RETURN OMV TO SPACE STATION AND REFURBISH.

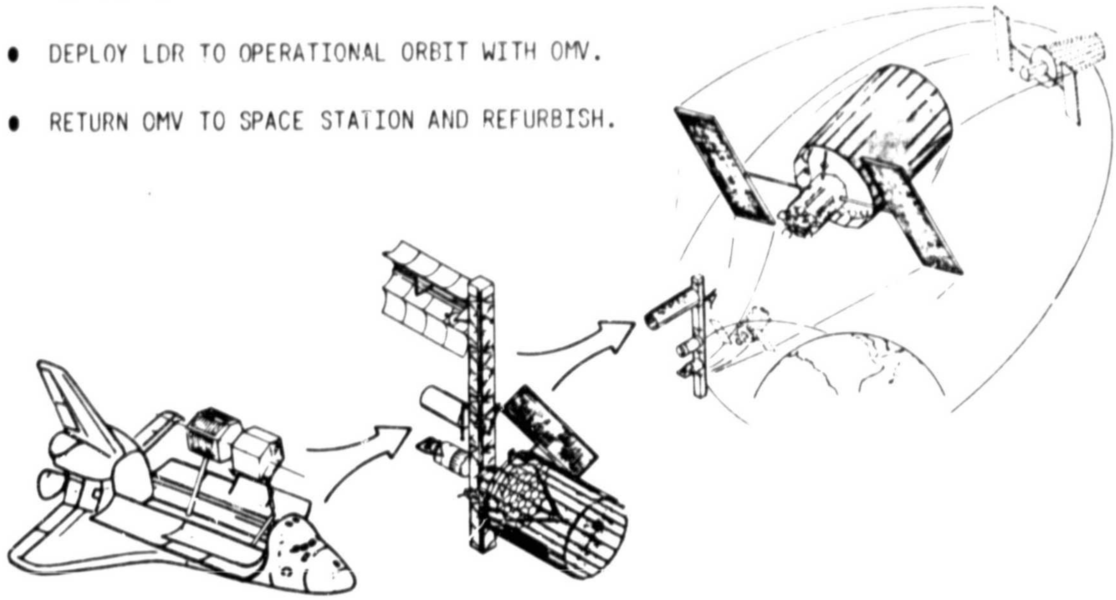

Figure 5.2.4-1 TDM 4 - Assembly of Large Spacecraft

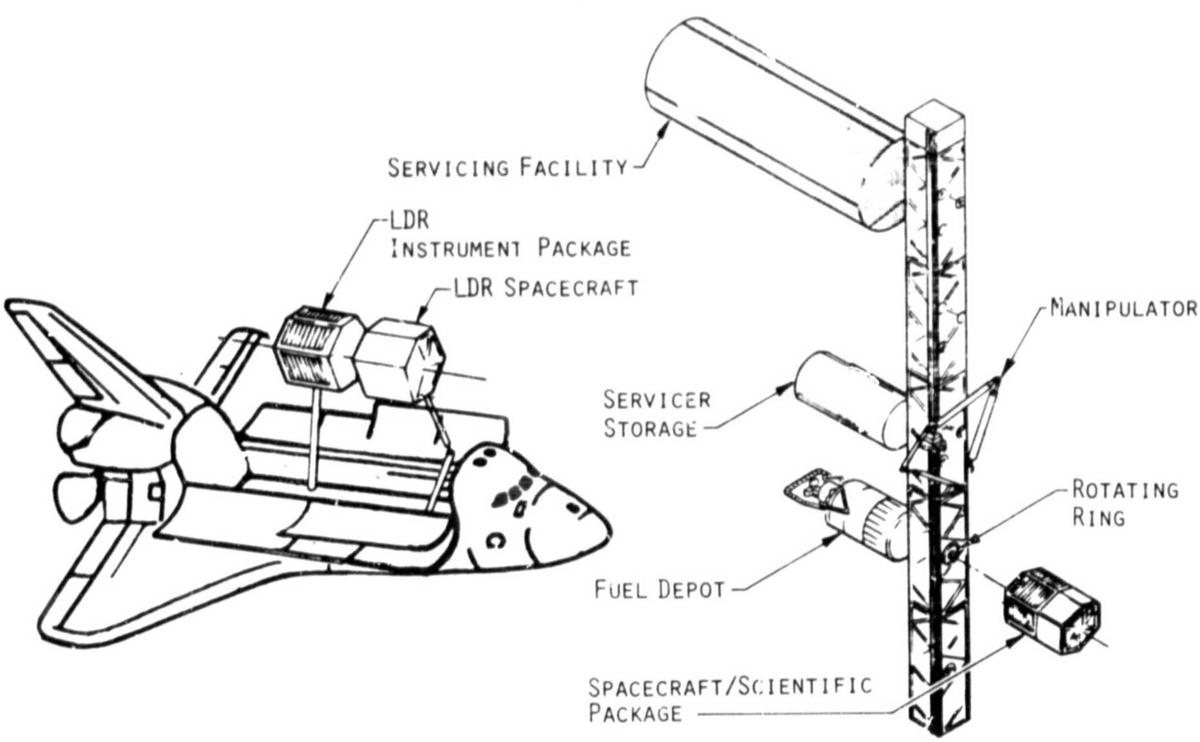

Figure 5.2.4-2 LDR Assembly - Phase 1

The next activity sequence in Phase 1 of the large spacecraft assembly TDM is the assembly of the LDR primary mirror segment clusters and attachment to the LDR spacecraft/scientific instrument elements. As shown on Figure 5.2.4-3, the STS cargo canister is used in this TDM to transport and store mirror cluster segments during an anticipated lengthy assembly period. The mirror segment clusters have a diameter roughly equal to the diameter of the STS cargo bay. Each cluster is comprised of seven 2-3 feet hexagonal mirrors. Each of these mirrors has a deployable support structure and three actuator mechanisms to enable individual alignment of each mirror, after the entire adaptive mirror system is assembled.

The graphic outlines transport of a primary mirror cluster (total of 19-20) to the primary mirror assembly area. The mirror cluster assemblies are aligned, attached and checked out, using the combination of a remotely operated manipulator mechanism and an astronaut on a mobile work station. The work station has movable manipulator foot restraints to provide astronaut stability for this precision assembly operation.

The actual assembly of the mirror cluster segments is the most stressing technical challenge in this TDM. Pre-alignment, then latching and post assembly alignment will be difficult. A software checkout program validating alignment accuracy (following assembly of the mirror segments), will be required. This alignment checkout procedure must be pre-tested on the ground and on the STS prior to initiation of this mission.

Another complex technical challenge relates to the need to retain the mirror segments free from contamination during the entire assembly process.

Phase 2 of the LDR assembly mission includes attachment of the secondary mirror subsystem to the mirror assembly, and attachment of the sunshade elements. These activity sequences are illustrated on Figure 5.2.4-4. These activities are conducted with a teleoperated SSRMS transporting assembly materials to the LDR, and astronauts performing the assembly operations. The assembly operations will be structured to enable maximum support from a translatable manipulator system. Advanced automation capabilities for the Space Station RMS are highly recommended to support difficult and time consuming assembly tasks and to increase man's productivity in these operations.

With these activities completed, the LDR assembly is complete. At this time, the LDR spacecraft and scientific instruments are rechecked, adaptive mirror segments are tested for effective alignment and the LDR is considered ready for transport.

The final activity sequence is illustrated at Figure 5.2.4-5. The LDR is grappled by the SSRMS and detached from the rotating ring. The OMV, having already been checked and grappled by the other manipulator arm, is mated with the LDR. OMV/LDR is deployed from the Space Station, using OMV inert gas proximity operations motors. The OMV/LDR Transfer Stack is launched to LDRs operational orbit. OMV is demated, using teleoperation from Space Station ground control, returned to Space Station and refurbished and reberthed for follow-on missions.

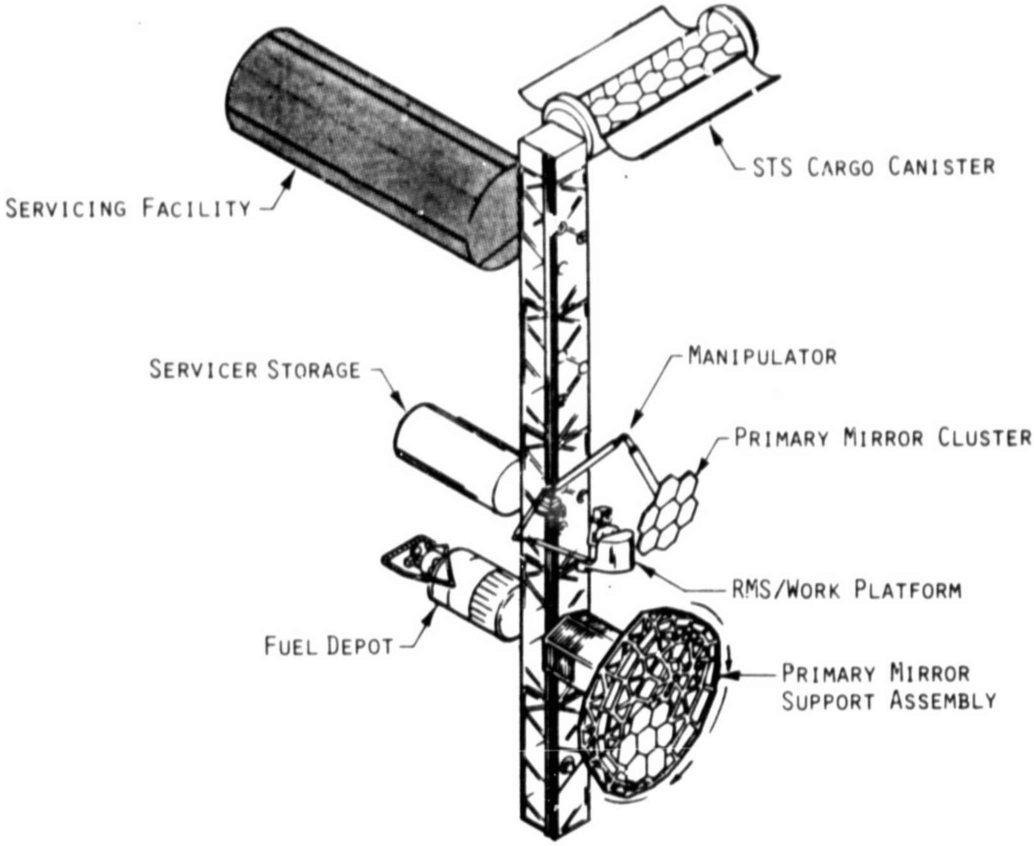

Figure 5.2.4-3 LDR Assembly - Phase 1

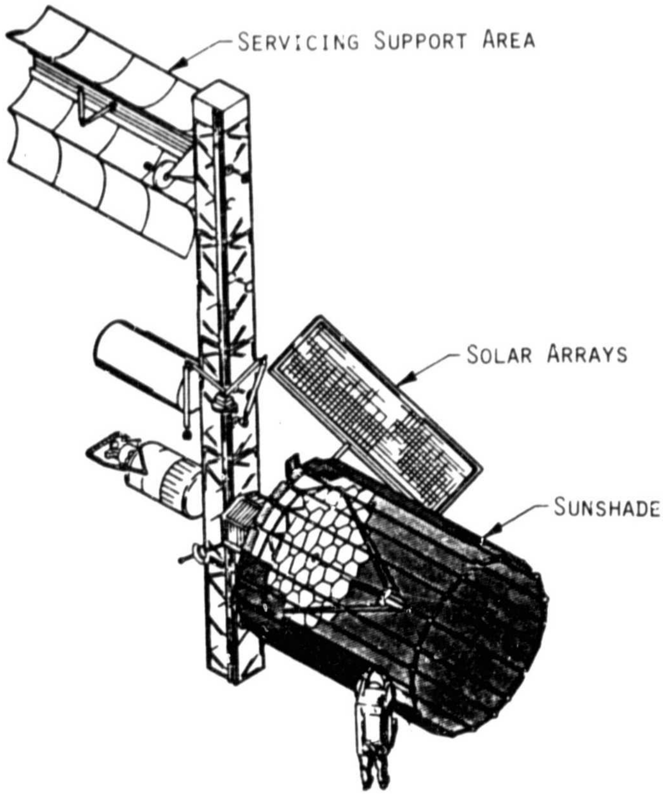

Figure 5.2.4-4 LDR Assembly - Phase 2

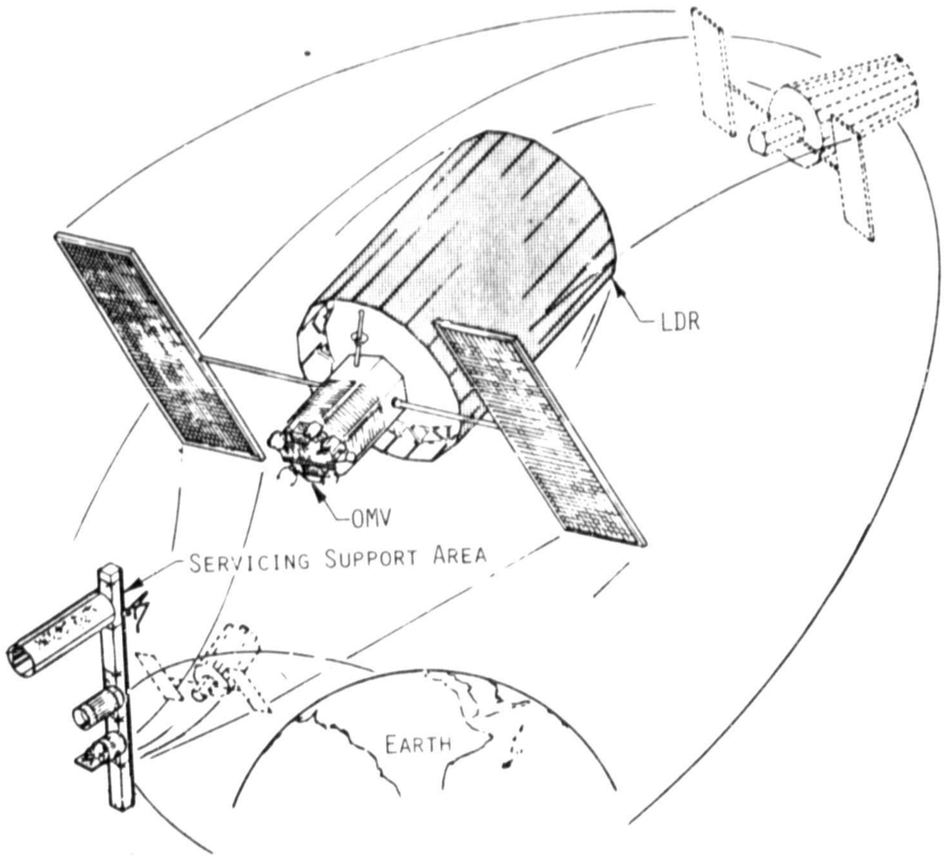

Figure 5.2.4-5 LDR Assembly/Deliver - Phase 3

This set of activities completes the summary outline of TDM 4, the onorbit assembly of LDR at the Space Station. Conduct of this mission in the late 1990s will demonstrate a significant new servicing capability at Space Station.

5.2.5 TDM 5 - Remote Repair By Intelligent Servicer

NASA MSFC requested Martin Marietta to develop a servicing scenario that would demonstrate increased satellite servicing capability at a mature Space Station. The scenario selected was to conduct a nearly autonomous fault isolation/system restoral operation on a disabled satellite located at the Experimental Geostationary Platform (XGP), in the late 1990s.

An outline of the principal TDM 5 activity sequences is illustrated on Figure 5.2.5-1. The first activity group, not unlike previously defined TDMs that involve activities remote from Space Station, involves preparation of the orbit transfer equipment. Thus as shown, an Orbital Transfer Vehicle (OTV), and the OMV and the Intelligent Servicer are fueled and loaded, mated and deployed from Space Station. The OTV then delivers the "Transfer Stack" to a rendezvous with the XGP in GEO, and the OMV and the attached Intelligent Servicer (IS) are separated. The OMV next rendezvous' and docks with the disabled satellite on the XGP. The IS, under SSGC, conducts a highly automated fault isolation and recovery process, under supervisory control from the ground. When the satellites' operation has been restored and operationally validated, the OMV returns to rendezvous and mate with the OTV. Finally, the OTV returns the Transfer Stack to Space Station, and all vehicles in the transfer operation are refurbished, reberthed and ready for their next missions.

The Intelligent Servicer is the primary new servicing element in this TDM. A representative dual armed Intelligent Servicer is shown mated to an OMV on Figure 5.2.5-2. The approach used in postulating a servicer for this mission was to; 1) identify relevant servicer technology elements (manipulators, sensors, computer vision, artificial intelligence/expert systems) out to the end of 1991; and 2) integrate appropriate evolving technology into an Intelligent Servicer design that could be developed and flown in 1996-97 to demonstrate the advances in servicing capability.

A top level functional analysis for TDM 5 is shown in Figure 5.2.5-3. This graphic further identifies the specific activities involved in the three primary phases of TDM 5. Phase 1 includes those activities required to prepare the servicing Transfer Stack, transfer it to the geostationary platform and then separate the OMV and Intelligent Servicer to dock with the inoperative satellite. Phase 2, as shown on Figure 5.2.5-3 outlines the activities connected with the actual repair mission, fault isolation and restoral. Phase 3 includes those activities related to returning the Transfer Stack to the Space Station and refurbishing the reusable vehicles; OTV, OMV and Intelligent Servicer.

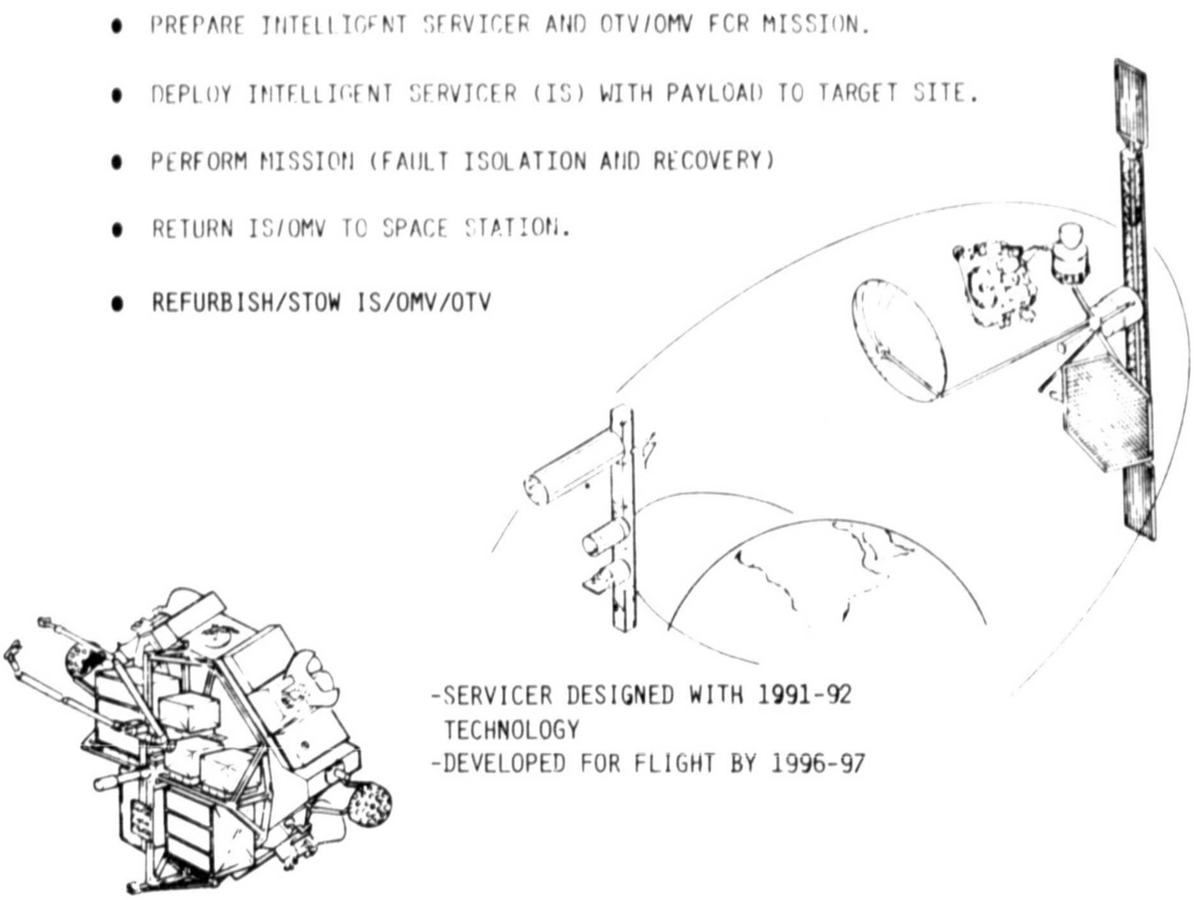

Figure 5.2.5-1 TDM 5 - Remote Repair by Intelligent Servicer

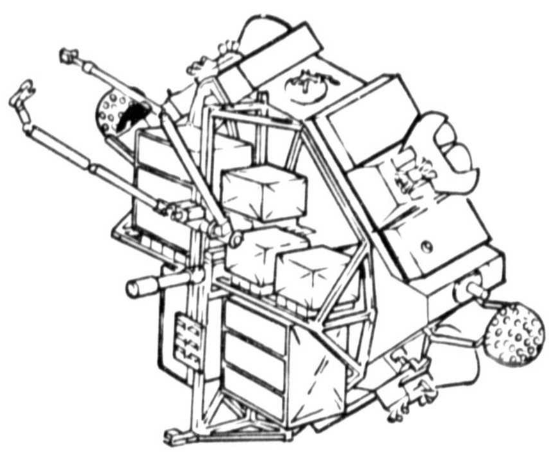

Figure 5.2.5-2 Intelligent Servicer

An expansion of Phase 2, the actual repair of the malfunctioning satellite at the XGP, is shown at Figure 5.2.5-4. The Intelligent Servicer is first docked at the disabled satellite at XGP. The IS is fixed firmly with stabilizer bars, and fault isolation umbilical connections are affected autonomously.

The fault isolation and detection process is initiated with the use of highly advanced artificial intelligence and manipulator systems operating interactively. The objective of this operation is to understand the work area. Normal operation of the satellite's system(s) has terminated for an unknown reason, and reevaluation of the satellite's configuration is paramount in importance. This is accomplished by comparing the new satellite configuration with the configuration known prior to the malfunction. Thus, an initial task is to conduct "image understanding" operations using advanced multiple arm manipulators, advanced sensors (proximity, tactile, force moment), 3-D lasers, computer vision systems and color stereo cameras. The new "work station" images are now correlated with stored system(s) design/malfunction data. The artificial intelligence system(s) perform comparative analyses, use advanced decision-oriented algorithms to isolate fault(s) and provide recommended restoral actions to a human in supervisory control of the repair operation at SSGC (ground control).

Restoral activities are directed by SSGC mission supervisor(s) and the expert system/manipulator system(s) conduct restoral operations including replacement of lowest replaceable unit(s) (LRUs) or malfunctioning/damaged system components, either in spacecraft or science instrument/payload elements.

In addition, most resuppliable satellite expendables; propellants, pressurants, batteries, instrument coolant and gases, etc., will be resupplied at this time, to support satellite life extension.

Following completion of all repair and resupply operations, ground control (SSGC or a POCC) will conduct operational checkouts of all satellite systems, will retract fault isolation cables and stabilizer support mechanisms and separate from the newly restored satellite.

All of these operations are conducted remotely, semi-automatically, with critical events under the control of humans at Space Station Ground Control.

The detailed definition of TDM 5 supported identification of a number of required technology developments essential to development of an Intelligent Servicer. These are shown on Figure 5.2.5-5. Though all are important, the key technology development areas are: artificial intelligence, including path planners, expert systems, natural language interfaces and advanced decisional algorithms; information processing, with mass memory and high speed signal processing advancements seen to be critical needs; and sensory perception, including vision and tactile, touch and proximity systems.

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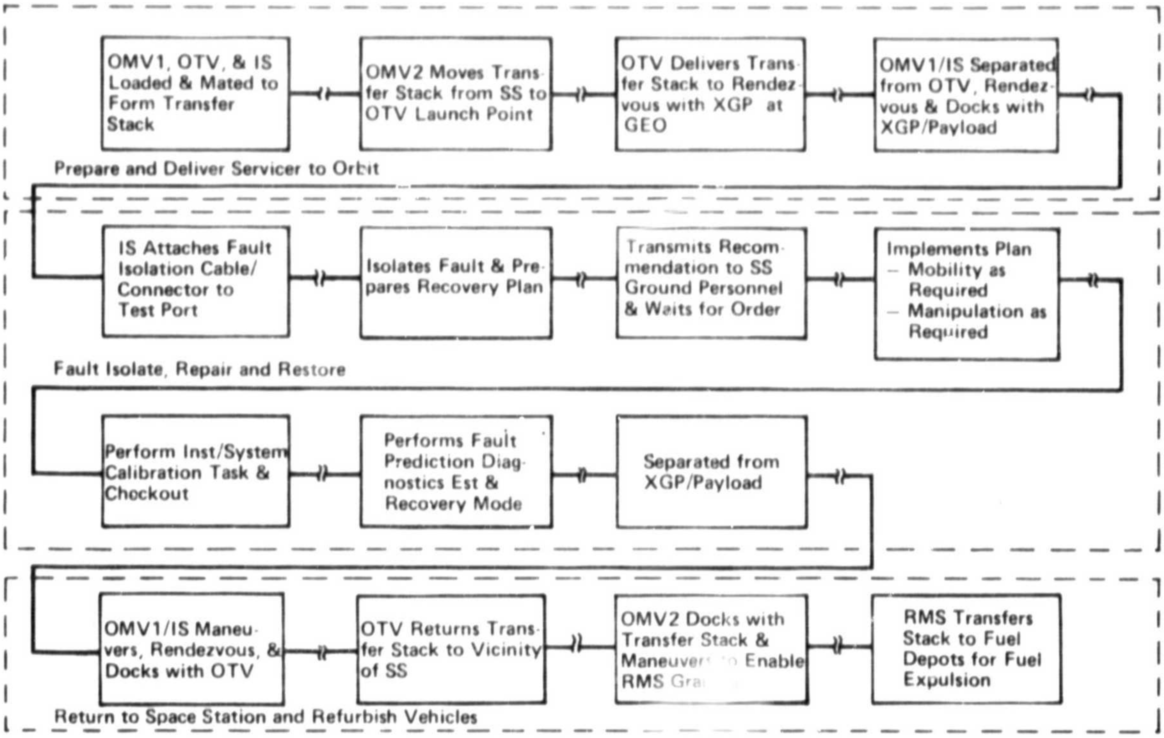

Figure 5.2.5-3 TDM 5 Scenario

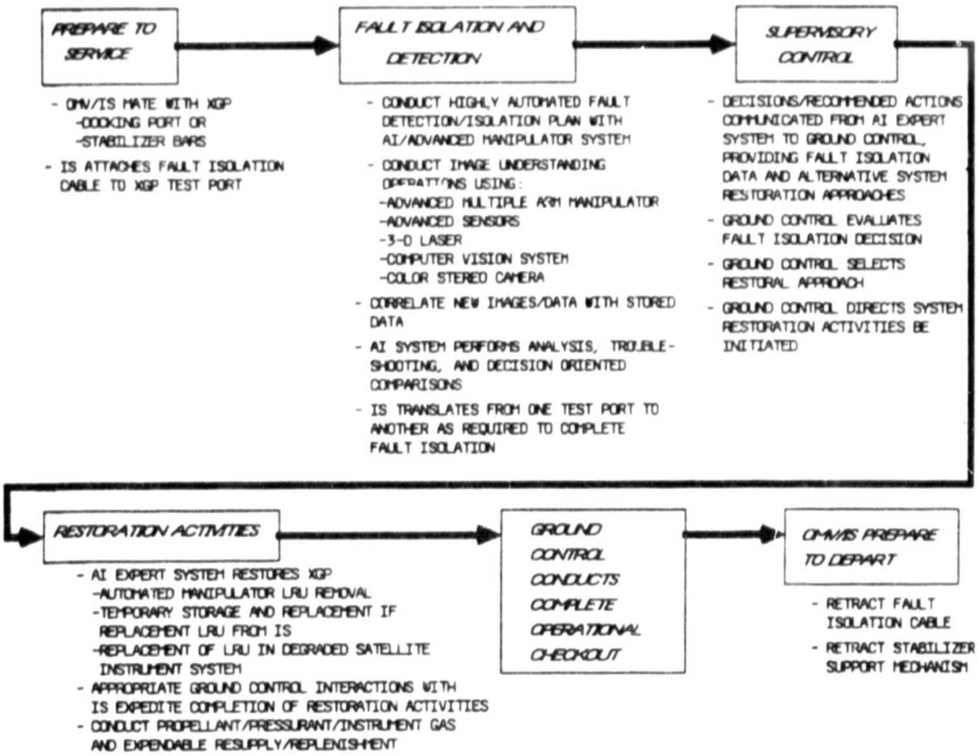

Figure 5.2.5-4 TDM Repair Events

A final summary inclusion for TDM 5 is a Technology Development/TDM Implementation Plan and Schedule, shown in Figure 5.2.5-6. This plan provides a roadmap for the technology development required to evolve the state of automation technology to the point where an intelligent servicer could be designed and developed. It also outlines the TDM activity timeline suggested to enable implementation of this sophisticated servicing mission in the late 1990s.

As shown, manipulator advancements, computer vision sensor advancements and artificial intelligence developments will evolve in parallel paths and at varying rates. Early in 1992, the development of Intelligent Servicer will be initiated, leading to ground, STS and Space Station test and validation. STS flight experiments are indicated with specified validation objectives.

TDM implementation activities will commence also in 1992, with ongoing coordination with both OTV and Intelligent Servicer programs. Following requisite precursor validation activities for OTV and Intelligent Servicer, both on STS and at the Space Station, TDM 5 could be conducted in 1997.

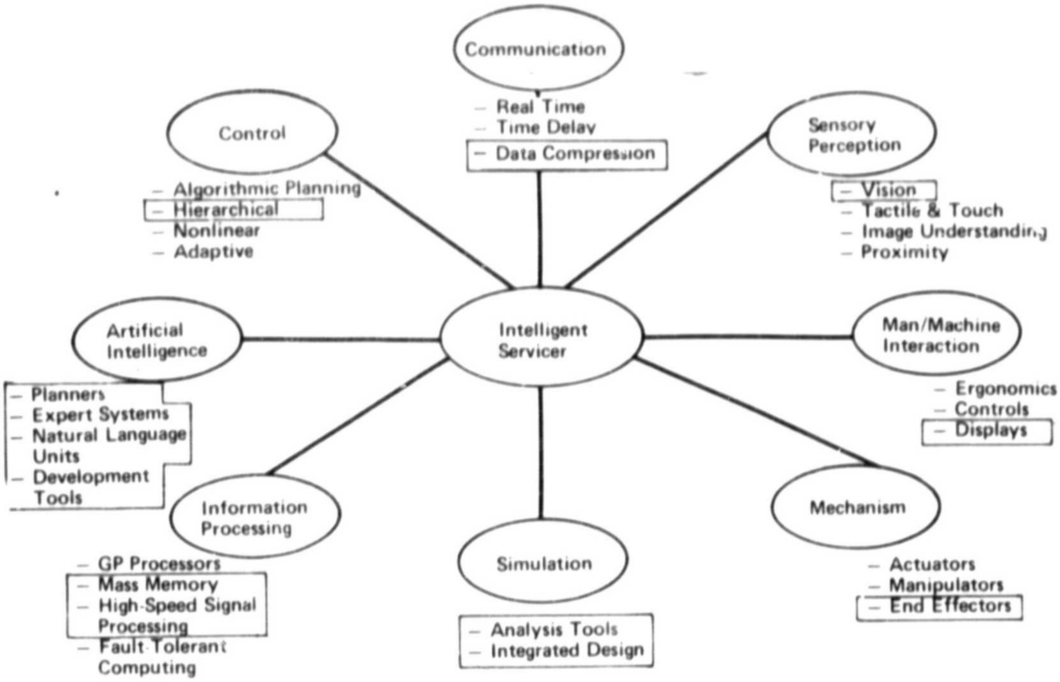

Figure 5.2.5-5 Technology Development for Intelligent Servicer

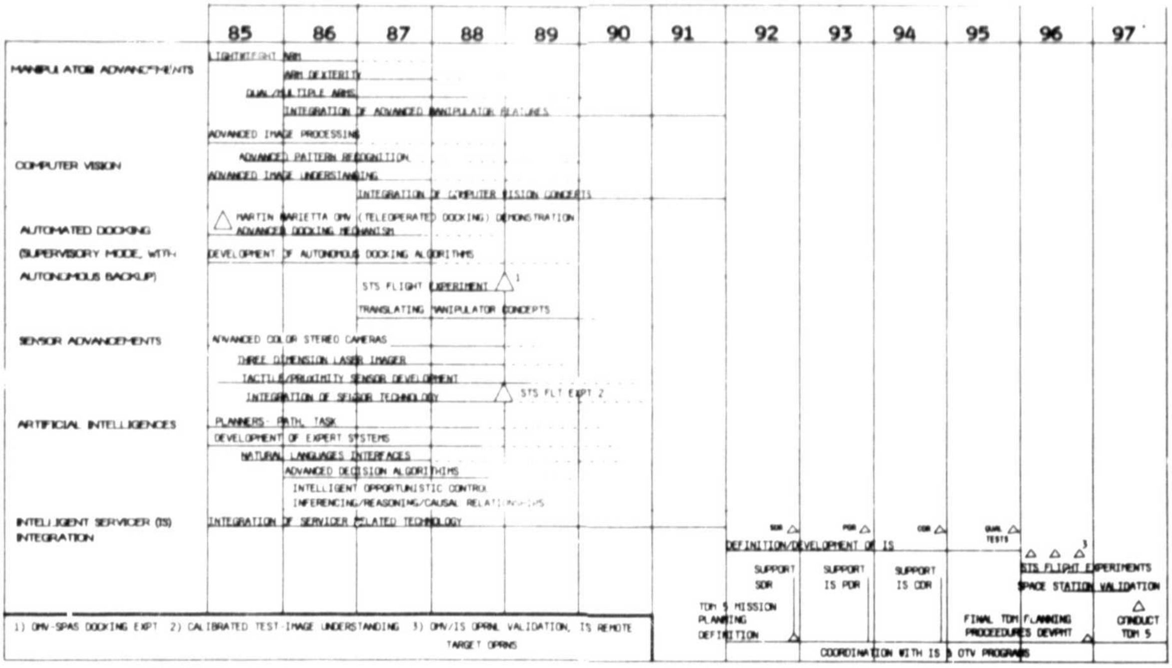

Figure 5.2.5-6 TDM 5 - Technology Development/TDM Implementation

6.0 DESIGN REQUIREMENTS ANALYSIS

6.1 Objectives and Approach

The principal objective of the Design Requirements Analysis task for the Phase 2 study was to expand and refine the existing knowledge base of Space Station satellite servicing accommodation needs; i.e., service hangars, storage facilities, reusable transfer vehicles, etc. A secondary objective was to establish a set of spacecraft design criteria to serve as guidelines for those planning to configure their satellites for servicing at the Space Station. An additional objective was to define servicing interface requirements and accommodations.

The design requirements analysis approach used by Martin Marietta is shown in Figure 6.1-1. As each of the TDMs were defined at expanding levels of detail, functional and operational analyses produced specific servicing requirements. These requirements were entered into a master requirements data base. There were many duplicative requirements, particularly related to EVA, OMV and MMU, as use of these equipments and operations were common in many of the TDMs. The requirements data base was constantly expanded and, when appropriate, requirements were purged to eliminate redundancy. Space Station accommodation needs were then developed from the derived servicing requirements. In addition, some selective design concepts were provided to illustrate potential approaches for satisfying the servicing needs. Finally, spacecraft servicing design criteria were outlined, and a Space Station servicing interface analysis was conducted to provide added insight to the total complement of satellite servicing requirements and accommodation needs.

6.2 Servicing Requirements/Accommodation Needs

With the completion of TDM detailed definition, the associated derived requirements data base was readied for refinement and definition of accommodation needs. This data base was thoroughly reviewed for redundancy. Next, the requirements were grouped into logical sets, to support definition of major categories of Space Station servicing elements and support equipment. These servicing elements, such as servicing hangar(s), servicing storage needs, and reusable transport vehicles, had been identified in the Phase 1 study and reverified as major servicing needs during Phase 2 analyses. This regrouping of servicing requirements is shown in Figure 6.2-1. The total set of requirements were classified as relating to; servicing facility, berthing/storage, fluid storage/transfer, satellite transport, and assembly.

The first category, those requirements identified as relating to a servicing hangar/facility, include: requirements to berth and stabilize a satellite for servicing, to support maintenance, repair and retrofit (MR&R) activities on satellites, and to provide satellite checkout, and mate and demate activities, to support servicing done in conjunction with satellite delivery and retrieval operations. These are representation top level requirements. A second example from Figure 6.2-1 is fluid storage and transfer.

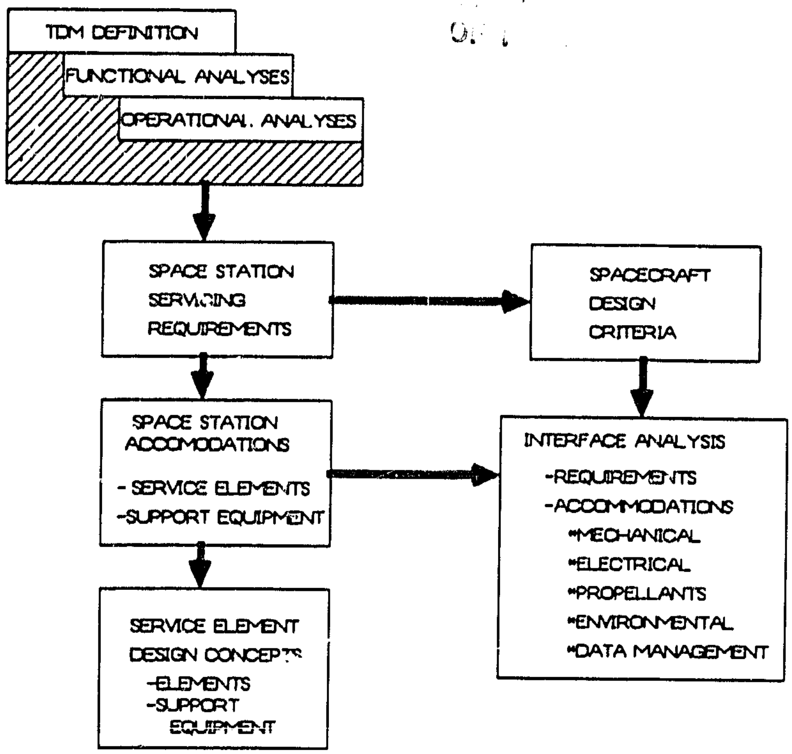

Figure 6.1-1 Design Requirements Analysis Process

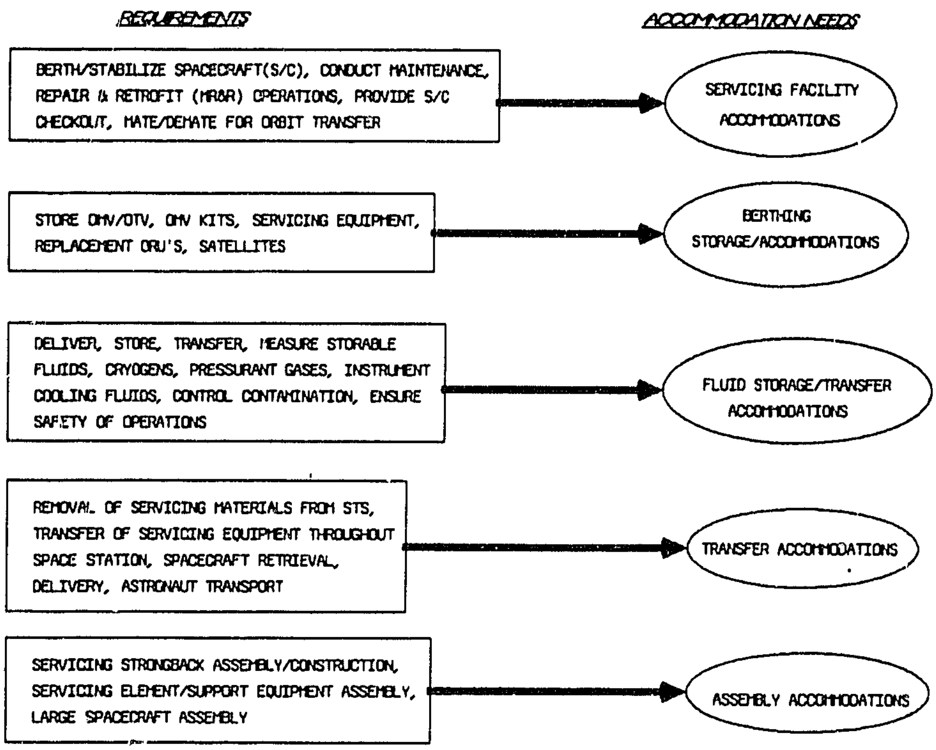

Figure 6.2-1 Space Station Servicing Requirements/Accommodations

Related requirements such as: deliver, store, supply/resupply and measure both storable fluids and cryogenics; control contamination relative to fluid transfer, and ensure safety of operations were grouped to support definition of the Space Station accommodation needs for storage and transfer of fluids.

The next phase of design requirements analysis involved the translation of requirements into specific Space Station elements and support equipment needed to facilitate servicing. An example of the result of this process is shown in Figure 6.2-2. The expanded grouping of requirements specifically related to the presumed need for a servicing hangar or servicing "facility" is displayed. These requirements are top level, but encompass a broad spectrum of the types and levels of servicing requirements that must be satisfied to enable satellite servicing. For the specific purpose of this study, requirements such as; provide full access to an AXAF spacecraft for MR&R activities, remove access panels, enable mating of OMV and AXAF or OMV front end kits, and contamination monitoring/shielding of spacecraft elements during replacement, will demand satisfaction to enable conduct of the selected TDMs.

The suggested accommodation needs, shown at the right side of Figure 6.2-2, are potential solution sets, designed to provide satisfaction of the identified servicing requirements. For example, a rotatable carousel berthing assembly, to be used for berthing and stabilizing satellites (and perhaps OMV), translatable work stations equipped with manipulator foot restraints (MFR), is one approach to satisfying the need to provide full access to AXAF for MR&R activities. A candidate design concept for the servicing hangar/facility is displayed in Figure 6.2-3. This servicing configuration provides: a thermal shield, with cargo bay like doors to provide access for RMS delivery of satellites and OMVs; a payload rotation/translation mechanism to berth satellites and allow spacecraft rotation and full access for repair operations; lighting, contamination monitors, equipment and spares storage lockers, and numerous other servicing features. These design concepts were not contractual requirements; they are provided to enhance the visual perception of Space Station servicing accommodations.

Another set of derived servicing accommodation needs is shown in Figure 6.2-4. Fluid storage and transfer requirements and accommodations were further subdivided into three branches, OMV, OTV and satellite/spacecraft. Requirements and recommended servicing elements and support equipment for each is outlined on the graphic. A representative storable fluid depot is provided in Figure 6.2-5. This conceptual fluid depot is configured to supply propellant fuels and pressurant gases for OMV and other spacecraft, and instrument coolant gases for science instruments. As a multi-purpose storable fluid depot, the design concept includes a carousel mechanism for berthing and rotating vehicles undergoing servicing. It is anticipated that highly automated fueling processes will be desired at Space Station and a robotic manipulator, the Integrated Orbital Servicing System (IOSS), is shown configured to robotically mate fueling umbilicals to spacecraft designed with standard fueling interfaces.

REQUIREMENTS

- BERTH OMV/SATELLITES
- STABILIZE FOR SERVICE OPERATIONS
- PROVIDE CONTAMINATION SHIELDING
- PROVIDE LIGHTING
- PROVIDE FULL ACCESS TO OMV/SPACECRAFT FOR M&R AND R*
- PROVIDE POWER/DATA HANDLING CHANNELS TO OMV/SPACECRAFT
- CONTAMINATION MONITORING/CONTROL/SHIELDING
- REMOVE ACCESS PANELS
- REPLACE MODULES
- REPLACE PRESSURIZED TANKS
- REMOVE/REPLACE INSULATION
- REMOVE REPLACEMENT ORU'S/PRESSURIZED TANKS FROM STORAGE
- DISPOSE OF USED ORU'S/PRESSURIZED TANKS
- SECURE ACCESS PANELS
- PROVIDE CHECKOUT CAPABILITY FOR OMV/SPACECRAFT
- ENABLE MATING OF OMV/SPACECRAFT
- PROVIDE DEBERTHING OF OMV/SPACECRAFT
- TRANSFER TO AMC FROM SERVICING FACILITY

* M&R AND R- MAINTENANCE, REPAIR, & RETROFIT

ACCOMMODATION NEEDS

- SAFETY EQUIPMENT, LIGHTING
- BERTHING MECHANISM(S)
- PAYLOAD CRADLE/CAROUSEL MECHANISM
- SPACE STATION RMS CONTROL CONSOLE
- MATING/DEMATING MECHANISMS, ALIGNMENT
- RMS ACCESS TO FACILITY FOR RECEIPT OF OMV/SPACECRAFT
  - COLLAPSABLE SHIELDING, OPENING SHELTER DOOR/SLIDING WALLS, NO SHIELDING
- THERMAL, RADIATION, MICROMETERIOD PROTECTION
- TRANSLATABLE WORK STATION(S)
- PAYLOAD SUPPORT: POWER/DATA HANDLING THERMAL
- COMMUNICATIONS
  - COMMAND/TELEMETRY VIA TDRSS TO SS GROUND CONTROL/POCC
  - CCTV AND VOICE
  - DATA DISPLAY, STORAGE, PROCESSING CONTROL
  - GPS DATA RECEPTION
- MODULE CHANGEOUT EQUIPMENT FIXTURES
- FOOT RESTRAINTS, HANDHOLDS
- CONTAMINATION MONITORING, SHIELDING
- STORAGE FOR EXPENDABLES, BATTERIES, TAPES

Figure 6.2-2 Servicing Facility Accommodations

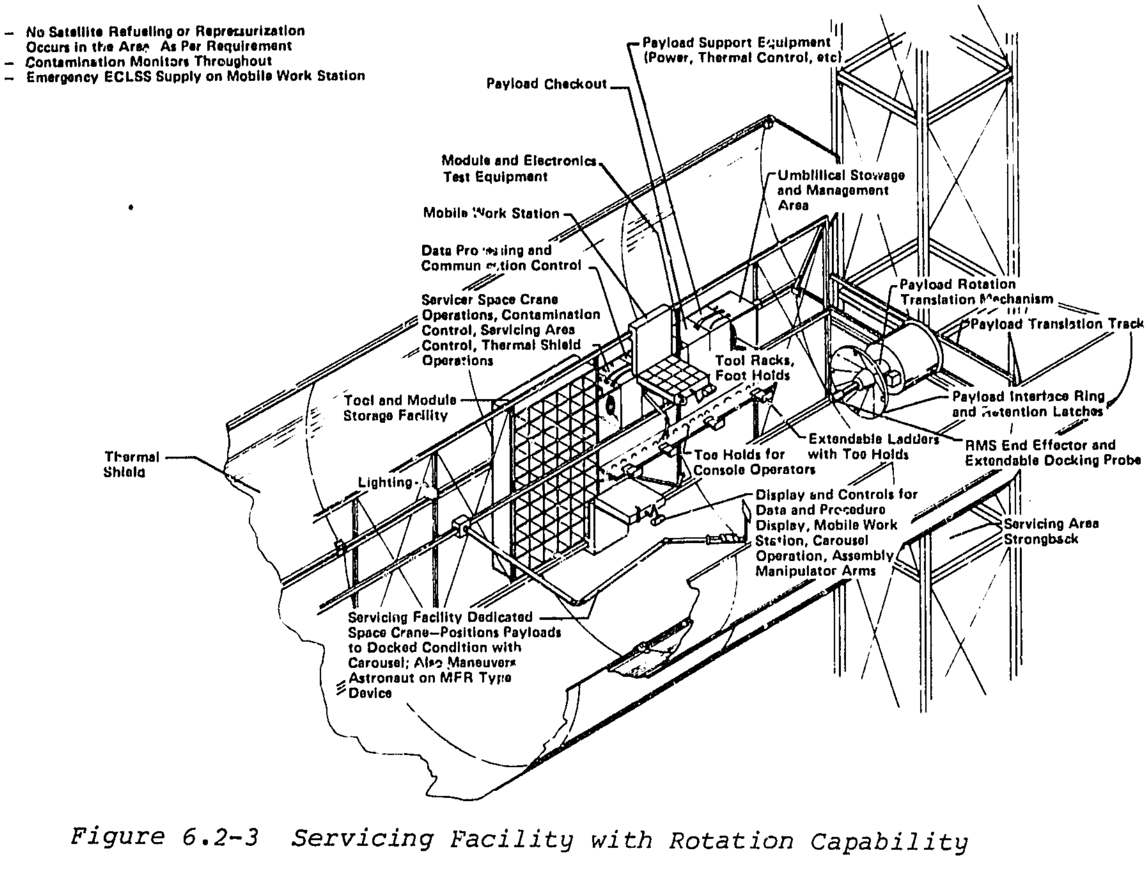

Figure 6.2-3 Servicing Facility with Rotation Capability

REQUIREMENTS	ACCOMMODATIONS
OMV	
- DELIVER BI-PROPELLANTS (MMH/NTO), PRESSURANT (HE), AND COLD GAS (N) TO SPACE STATION - STORE IN FACILITY DESIGNED FOR TRANSFER - TRANSFER TO OMV, MEASURE AMOUNT TRANSFERRED, RESIDUAL FLUIDS - MONITOR, CONTROL CONTAMINATION - ENSURE SAFETY OF OPERATIONS	- BERTHING FOR OMV AT FUEL DEPOT - OMV FUEL DEPOT TO STORE/TRANSFER PROPELLANTS, PRESSURANTS AND COLD GASES - AUTOMATED, ROBOTIC UMBILICAL QUICK CONNECT/DISCONNECT FOR TRANSFER OPERATIONS - CONTAMINATION MONITOR, CONTROL EQUIPMENT, SHIELDS - VENTING EQUIPMENT
OTV	
- DELIVER CRYOGENS, PRESSURANTS - STORE IN FACILITY DESIGNED FOR TRANSFER - TRANSFER TO OTV, MEASURE AMOUNT TRANSFERRED, RESIDUAL FLUID - MONITOR, CONTROL CONTAMINATION - ENSURE SAFETY OF OPERATIONS	- BERTHING FOR OTV AT FUEL DEPOT - CRYOGEN STORAGE/SUPPLY TANKS CAPABLE OF TRANSFER TO OTV - AUTOMATED, ROBOTIC CHILLDOWN, FLUID TRANSFER, UMBILICALS, AUTOMATED INTERFACE ALIGNMENT - CONTAMINATION MONITOR, SHIELDS, CLEAN UP CONTROL EQUIPMENT
SATELLITE/SPACECRAFT	
- DELIVER STORE PROPELLANTS, PRESSURANTS, INSTRUMENT GASES - TRANSFER TO VEHICLES, MEASURE AMOUNT DELIVERED, RESIDUAL FLUID - MONITOR, CONTROL CONTAMINATION - ENSURE SAFETY OF OPERATIONS	- SPACECRAFT BERTHING AT FLUID DEPOT - SPACECRAFT PROPELLANT, PRESSURANT INSTRUMENT STORAGE/SUPPLY TANKS FOR FLUID TRANSFER, REPLACEMENT TANKS/BOTTLES - FLUID TRANSFER INTERFACE MECHANISMS - CONTAMINATION SHIELDING, MONITOR SYSTEM, CONTROL/CLEAN UP EQUIPMENT

Figure 6.2-4 Fluid Storage/Transfer Accommodations

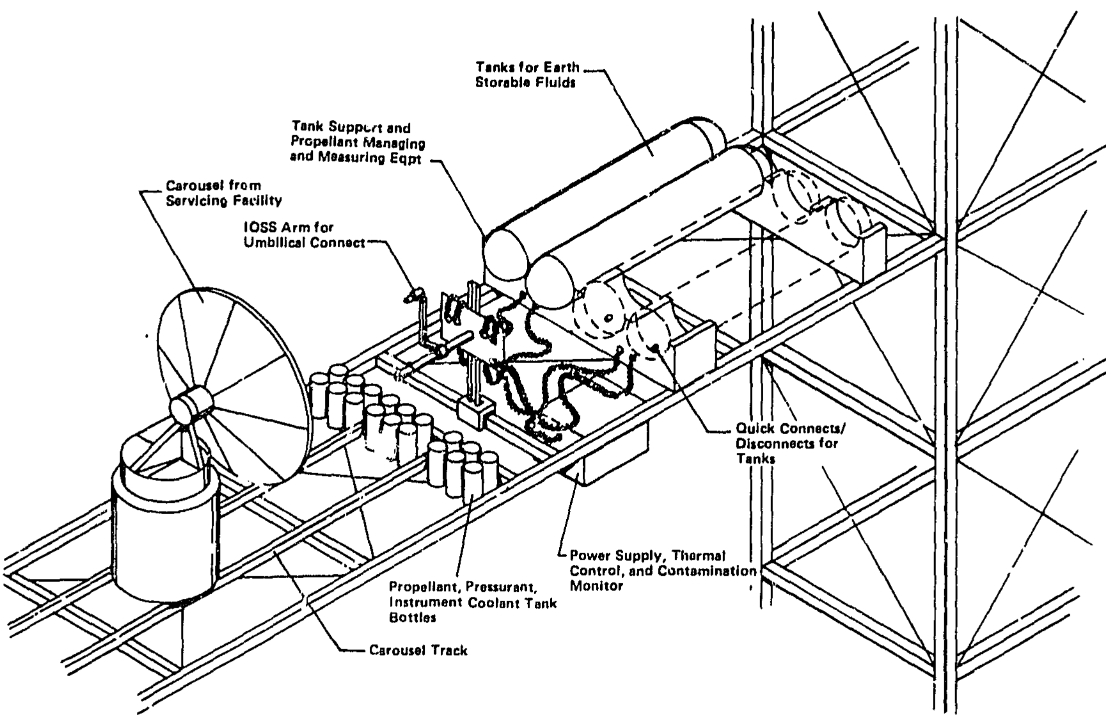

Figure 6.2-5 Storable Fluid Depot

6.3 Spacecraft Design Criteria

One specific Martin Marietta objective in the Design Requirement Analysis process was to provide top level design criteria to serve as a reference point for planners configuring spacecraft for eventual onorbit servicing at or from the Space Station. With Space Station undefined, and standard satellite/spacecraft servicing interfaces still largely undefined, a detailed definition of servicing design criteria would be premature. However, from servicing operations already conducted on STS and with others planned, an outline of design criteria for eventual servicing at Space Station can be initiated. This outline is shown at Figure 6.3-1. Servicing design criteria are classified according to type of servicing activity. These include; resupply activities, such as ORU replacement, or replacement of batteries, film and other expendables; satellite maintenance repair and retrofit (MR&R); fluid transfer; and orbit transfer, either delivery or retrieval.

Spacecraft designers must first assess requirements for resupply of expendables, which primarily provides extension of onorbit satellite lifetimes. Developers must evaluate and compare planned <u>satellite lifetimes</u> with the expected satellite <u>payload technology cycle</u>, to ascertain whether servicing resupply activities are warranted. Then, given that the satellite will be designed for resupply, the designers should consider several factors including: standard mountings and interfaces for ORU replacement, standard alignment processes, use of standard tools, accessibility for both EVA and robotic resupply operations, and safety.

For designers planning to accommodate satellite repair activities, a first consideration relates to how the repair operation can most effectively be accomplished, for instance, either by man or by machine. EVA capability has been demonstrated, but has been shown to be difficult and inefficient, in the zero-gravity environment. On the other hand autonomous systems, though expensive to develop, can pay off over time with frequently used, multi-purpose equipment. In discussions with automation experts, it has been recommended that subsystems be designed for automatic fault isolation, detection and restoral. Solar Maximum repair experience and planned recovery operations for the Westar and Polapa communications satellite retrieval mission, highlight the benefits of providing redeployable, retractable appendages, where possible, to reduce clearance envelope problems and prevent loss of operating subsystems during repair.

Servicing design criteria considerations are also shown for planners considering onorbit fluid transfer and either delivery or retrieval operations with OMV or OTV.

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- MODULAR ORBITAL REPLACEMENT UNIT (ORU) REPLACEMENT/BATTERIES/EXPENDABLES

- DESIGN FOR OPTIMUM ORU REPLACEMENT
  - SPACECRAFT MODULES, INSTRUMENTS
  - EXPECTED LIFETIMES, TECHNOLOGY UPGRADE CYCLE
- STANDARD MOUNTING, INTERFACE FITTINGS, FASTENERS
- STANDARD COURSE/FINE ALIGNMENT TECHNIQUES: PIN, SLOT, KEYS
- PROVIDE ACCESSIBILITY: EVA, ROBOTIC OPERATIONS
- DESIGN FOR MAXIMUM USE OF MULTI-PURPOSE TOOLS, MINIMIZE UNIQUE TOOLS
- SAFETY: MINIMUM ASTRONAUT INTERFACE WITH STORED ENERGY, PYROTECHNIC DEVICES
- DESIGN IN MODULARITY FOR FLEXIBLITY, GROWTH
- PROVIDE HANDHOLDS NEAR ORU CENTER OF GRAVITY
- MAINTAIN CONFIGURATION CONTROL

- SATELLITE REPAIR

- CONSIDER EVA/AUTOMATION ROBOTICS TRADES
  - EVA CAPABILITY NOW PROVEN
  - EVA OPERATIONS DIFFICULT, INEFFICIENT
  - AUTOMATED SYSTEMS, ROBOTICS EXPENSIVE
- DESIGN SUBSYSTEMS FOR AUTOMATIC FAULT ISOLATION, DETECTION, RECOVERY PROCESSES
- PROVIDE RETRACTABLE APPENDAGES
  - REDUCE CLEARANCE ENVELOPE PROBLEMS
  - PRECLUDE UNNECESSARY LOSS OF FUNCTIONING HARDWARE
- PROVIDE HANDHOLDS, TETHER ATTACH POINTS, AND FOOT RESTRAINT SOCKETS
- STANDARD COLOR CODES, MARKINGS, LABELS FOR EASE IN IDENTIFICATION

- ONORBIT FLUID TRANSFER

- DESIGN FOR EVA, REMOTE/AUTOMATED FLUID TRANSFER
- PROVISION FOR HOLDING: STS TRUNNION FITTINGS, CAROUSEL MATING
- ACCESSIBILITY FOR STANDARD UMBILICAL CONNECT: EVA, ROBOTIC
  - POWER - VENTING - CRYOGENS - COOLANTS
  - DATA - PRESSURANTS - EARTH STORABLE
  - COMBINATIONS
- PROVIDE CONTAMINATION SHIELDING, CONTAMINATION CONTROL MEASURES
  - COMPATIBLE WITH DECONTAMINATION EQUIPMENT

- ORBIT TRANSFER: DELIVERY, RETRIEVAL

- CONFIGURE SPACECRAFT FOR MATING WITH OMV/OTV
- COMPATIBLE WITH MANUAL/AUTOMATED ALIGNMENT PROCESSES, MATING LOADS
- COMPATIBLE WITH, ACCESSIBLE TO POWER, DATA UMBILICALS/INTERFACES FOR OPERATIONAL CHECKOUT AT SPACE STATION
- PROVISION FOR RETRIEVAL
  - SPACECRAFT INERTING
  - CONTAMINATION SHIELDING, DUST COVERS
  - RETRACTABLE APPENDAGES

Figure 6.3-1 Spacecraft Design Criteria for Space Station Servicing

6.4 Space Station Servicing Interface Requirements

Interfaces between satellites, OMV, OTV and other "serviced" systems; and Space Station servicing components, were identified while conducting functional and operational analyses during TDM definition. From the "interface data base", all unique interfaces (redundant interfaces eliminated) were evaluated to determine their physical and operational characteristics. The interface requirements were categorized as; structural/mechanical, electrical (power and data), environmental, fluids, crew and communications. The specific interface requirements for each of these classifications, as they relate to defined TDMs in this study, were described. Requirements for structural/mechanical interfaces are shown on Figure 6.4-1, and for environmental interfaces on Figure 6.4-2, as examples of the results produced from these analyses.

- SPACE STATION RMS WITH END EFFECTORS TO GRAPPLE:
    - GRAPPLE FIXTURES - OMV, OTV, AXAF, LDR ELEMENTS
- UMBILICAL CONNECTION DEVICE/UMBILICAL DISCONNECTION ACTUATION DEVICE
    - SERVICE/POWER UMBILICAL AT OMV AND OTV STORAGE SITES
    - ELECTRICAL UMBILICAL AT OMV AND OTV STORAGE SITES
    - FUELING/ELECTRICAL UMBILICAL AT OMV AND OTV FUEL DEPOT.
- BERTHING STRUCTURES AND LATCHES - WITH AUTOMATIC LATCH ACTUATION/RELEASE MECHANISM - TO FORM STABLE PHYSICAL CONNECTION BETWEEN:
    - OMV AND OMV FUEL DEPOT
    - OMV AND SERVICE HANGER
    - OMV AND OMV STORAGE SITE
    - AXAF AND TEMPORARY BERTH SITE
    - AXAF AND SERVICE HANGAR
    - OTV AND STORAGE SITE
    - OTV AND OTV FUEL DEPOT
    - OTV AND SERVICE HANGAR
    - OMV/SERVICER AND SERVICER STORAGE SITE
    - OTV AEROBRAKE HANDLING FIXTURE
    - STORAGE FIXTURE FOR OTV ENGINE
    - FOUR RESTRAINTS AND TETHER ATTACHMENTS
    - SPACECRAFT LARGE COMPONENT STORAGE SUPPORT FIXTURE IN SERVICE HANGAR

Figure 6.4-1 Structural/Mechanical Interface Requirements

- ADEQUATE LIGHTING FOR VIDEO AT:
    - OVER SPACE STATION FOR TRANSFERS BETWEEN ELEMENTS
    - INSIDE SERVICE HANGAR FOR:
        - EXTERNAL VISUAL INSPECTION OR SPACECRAFT
        - VISUAL MONITOR OF SPACECRAFT DURING CHECKOUT
        - SPACECRAFT AND VEHICLE ALIGNMENT, BERTHING OPERATIONS
        - VERIFICATION OF SERVICE/POWER UMBILICAL CONNECTION
        - MONITORING OF EVA OPERATIONS, MATING AND DEMATING
    - OMV STORAGE SITE, OTV STORAGE SITE, SERVICER/ORU STORAGE SITES
    - OMV AND OTV FUEL DEPOT
    - SPACECRAFT DEPLOY AND CAPTURE SITES
- CONTAMINATION MONITORS AT:
    - MONITORS IN OMV AND OTV STORAGE SITES
    - OMV AND OTV FUEL DEPOTS
    - SPACECRAFT/SATELLITE
    - SATELLITE SERVICING HANGAR
- PROVIDE SOLAR RADIATION, THERMAL, MICROMETEOROID PROTECTION SHIELDING AS NECESSARY TO:
    - OMV AT OMV STORAGE SITE, SERVICING SITE
    - OTV AT OTV STORAGE SITE, SERVICING SITE
    - SATELLITES IN TEMPORARY STORAGE
    - SERVICERS (OMV KITS) AT STORAGE SITE
    - SATELLITES IN SERVICING HANGARS

Figure 6.4-2 Environmental Interface Requirements

7.0 TECHNOLOGY AND FLIGHT EXPERIMENT PLAN

7.1 Introduction

The objective of this Phase 2 study task was to develop a plan that would incorporate both: 1) the basic technology development required to enable Space Station servicing, and 2) the STS and Space Station flight experiments required to validate this servicing related technology. The result produced was an integrated, time-phased plan for technology development and flight validation that supports implementation of the selected TDMs. The approach used was; to collect all precursor technology activities identified in definition of the five TDMs, to collect and classify servicing technology requirements, to outline STS and Space Station onorbit validation flights/tests, and, finally, produce the plan.

7.2 TDM Precursor Activities

During Phase 1 and continuing into Phase 2 of the Satellite Servicing study, the importance of identifying precursor activities became increasingly clear. Precursor activities include; basic technology development required to support servicing; and definition, development and onorbit validation of Space Station servicing elements and servicing support equipment. All precursor activities must be identified, prioritized, planned and conducted along timelines that will enable conduct of TDMs designed to demonstrate specific servicing capabilities at the Space Station. Precursor activities for the five TDMs were collected and are shown in summary form on Figure 7.2-1.

7.3 Technology Development Requirements

During the TDM Detailed Definition phase of the study, a "technology development" data base was established, similar to the servicing requirements data base. This data base was developed through analyses of TDM precursor activities. These analyses supported identification of technology development requirements. Following completion of TDM definition, the technology development data base was inspected to ensure completeness and to eliminate redundant entries. The technology development file was then subdivided to group requirements into seven technology development areas.

These categories are outlined in Figure 7.3-1, and include; fluid transfer management, space-based reusable low energy upper stage (OMV), space-based reusable high energy upper stage (OTV), maintenance, repair and retrofit operations, remote servicing, large object handling and translation and, finally, servicing automation. An example of the specific technology development requirements identified for three of these categories is shown at Table 7.3-1.

TDM 1 - MATERIALS PROCESSOR RESUPPLY
- VALIDATION OF SPACE BASED, REUSABLE OMV
- FLUID TRANSFER MANAGEMENT TECHNOLOGY
- OMV FUEL DEPOT
- TELEOPERATED/AUTONOMOUS DOCKING
- TELEOPERATED MODULE REPLACEMENT
- INTELLIGENT FRONT END FOR OMV
- TRANLATABLE MANIPULATOR FOR OMV/MODULE TRANSPORTER
- MATERIALS PROCESSING MATURITY

TDM 2 - AXAF RETRIEVAL/REPAIR
- OMV VALIDATION
- FLUID TRANSFER MANAGEMENT
- OMV FUEL DEPOT
- SPACE STATION SERVICING SUPPORT AREA VALIDATION
- AXAF SUPPORT EQUIPMENT-ORU CARRIER
- SERVICING CAPABILITIES:ORU'S, MIRROR ASSEMBLY, SOLAR PANEL ALIGNMENT/REPLACEMENT
- EVA ENHANCEMENTS-IMPROVED SUIT, HEAD'S UP DISPLAYS
- SPACECRAFT FLUID DEPOT

TDM 3 - SPACE STATION ASSEMBLY/MODIFICATION
- DUAL ARMED, TRANSLATING MANIPULATOR, OR SPACE CRANE
- STRUCTURAL CONCEPTS, STRONGBACK ASSEMBLY, DEPLOYABLE STRUCTURES
- STORABLE FLUID/FUEL DEPOT(S)-OMV, SATELLITES
- TRANSLATABLE WORK STATION IN SERVICE FACILITY
- VALIDATE STORAGE FACILITIES-SATELLITES, OMV, ORUS, MMU EQUIPMENT, TOOLS
- LIGHT WEIGHT SHIELDING MATERIALS, ASSEMBLY PROCESS
- LIGHTWEIGHT CARGO CANNISTERS

TDM 4 - LARGE SPACECRAFT ASSEMBLY
- ON-ORBIT ASSEMBLY OF ADAPTIVE OPTICAL SYSTEM
- TRANSLATABLE, DUAL ARMED MANIPULATOR
- TRANLATABLE, WORK PLATFORM/CONTROL STATION
- LIGHTWEIGHT CARGO CANNISTERS
- VALIDATION OF LARGE ASSEMBLY OPERATIONS IN UNSHIELDED MODE
- CONTAMINATION P ROTECTION OF MIRROR SEGMENTS DURING ASSEMBLY

TDM 5 - INTELLIGENT SERVICER
- MANIPULATOR ADVANCES
- COMPUTER VISION
- AUTOMATED/AUTONOMOUS DECKING
- SENSOR ADVANCEMENTS
- ARTIFICIAL INTELIGENCE
- INTELLIGENT SERVICER SYSTEM
- OTV VALIDATION
- CRYOGENIC FLUID MANAGEMENT TECHNOLOGY

Figure 7.2-1 TDM Precursor Activities

TECHNOLOGY DEVELOPMENT REQUIREMENTS

-FLUID TRANSFER MANAGEMENT
  -STORABLE, CRYOGEN
  -STORAGE, TRANSFER RESUPPLY
  -STANDARD INTERFACES, QUICK DISCONNECTS

-SPACE-BASED, REUSABLE, LOW ENERGY UPPER STAGE (OMV)
  -REFUEL, REFURBISH
  -RENDEZVOUS-GPS, TDRS, NEW GN&C ALGORITHMS
  -DOCKING-GROUND CONTROLLED, TELEOPERATED

-SPACE-BASED REUSABLE HIGH ENERGY UPPER STAGE (OTV)
  -CRYOGENIC FLUID TRANSFER MANAGEMENT
  -AERO-ASSIST (BRAKING)
  -STORAGE, SERVICE, REFURBISH

-SPACE STATION MAINTENANCE, REPAIR & RETROFIT OPERATIONS
  -ADAPTIVE MIRROR SEGMENT ASSEMBLY
  -CONTAMINATION/DEGRADATION PREVENTION/MAINTENANCE
  -SATELLITE REPAIR, MATING, CHECKOUT, TRANSPORT

-REMOTE SERVICING (OMV KITS, ADVANCED SERVICER)
  -AUTOMATED/TELEOPERATED MODULE REPLACEMENT
  FLUID TRANSFER, REPAIR

-LARGE OBJECT MANIPULATION/TRANSLATION
  -LARGE SPACECRAFT ASSEMBLY, TRANSFER
  -OTV/SPACECRAFT FUELING, MATING, TRANSLATION

-SERVICING AUTOMATION
  -ARTIFICIAL INTELLIGENCE
  -SENSORS
  -IMAGE UNDERSTANDING
  -MANIPULATOR ADVANCES

Figure 7.3-1 Technology Development Overview

Table 7.3-1 Technology Development Requirements

-FLUID TRANSFER MANAGEMENT

-STORABLES, CRYOGENS

-SUPPLY, STORAGE

-FLUID TRANSFER, RESUPPLY

-THERMAL, PRESSURE CONTROL

-SAFETY, VENTING, CONTAMINATION

-STANDARD INTERFACES, QUICK DISCONNECTS

-AUTOMATION FOR SAFETY, EFFICIENCY FOR REPETITIVE OPERATIONS

-SPACE-BASED, REUSABLE, LOW ENERGY UPPER STAGE (OMV)

-FLUID TRANSFER-FUELS, PRESSURANTS, COLD GAS (FOR PROXIMITY OPERATIONS)

-RENDEZVOUS-USE OF GPS HARDWARE FOR OMV POSITIONING/ TDRS FOR TARGET POSITIONING/NEW GN&C ALGORITHMS

-DOCKING-OMV CAMERA USED TO ACHIEVE GROUND CONTROLLED TELEOPERATED DOCKING

-SPACE BASED, REUSABLE HIGH ENERGY UPPER STAGE (OTV)

-CRYOGEN FLUID MANAGEMENT

-AERO-ASSIST (BRAKING)

-DESIGN FOR SERVICING

-MODULARIZATION-COMPONENT GROUPING

-ADVANCED ENGINE

-PERFORMANCE, LIFETIME

-ADAPTIVE CONTROLS, HEALTH MONITORING, FAULT ISOLATION

Onorbit fluid transfer management is recognized as one of the most important technology development requirements presently associated with satellite servicing. The capability to store fluids, both storable and cryogenic liquids, and transfer them to reusable OMV and OTV transfer craft, and to satellites requiring resupply of fuels, pressurant and instrument gases will be essential for servicing at Space Station. Some of the basic technology issues related to fluid transfer management are: establishment of initial conditions in receiver tanks, accuracy of measurement, control of thermal and pressure conditions, venting and contamination and quick disconnects and standard fluid transfer interfaces.

Technology development issues relevant to OMV are also shown, and development of fluid transfer and onorbit storage capabilities are considered crucial. In addition, for rendezvous operations, the development and use of Global Positioning Satellite (GPS) hardware for OMV positioning, Tracking and Data Relay Satellite Systems (TDRSS) for target positioning and the development and validation of new guidance, navigation and control (GN&C) algorithms, are required. For remote docking of OMV with free-flyer satellites and platforms, demonstration of a ground-controlled, teleoperation docking capability is an additional technology challenge.

OTV technology development requirements were identified by review of documented OTV studies and was supported by insight from the Martin Marietta Phase A study team. OTV technology issues include cryogenic fluid management, an area in which Martin Marietta is presently heavily engaged. Denver Aerospace is presently engaged in detailed design of the Cryogenic Fluid Management Facility, intended to provide an onorbit facility for exploration and resolution of cryogenic fluid management issues. The design and development of an aero-assisted brake is considered essential, to reduce fuel requirements for OTV missions and inherently increase allowable payload weight for transfer to high energy orbits.

7.4 STS Flight Experiments

During TDM Definition, STS flight experiment requirements were also established and maintained in a specific data base. An early example of this data base is presented in Figure 7.4-1. These candidate STS flight experiments were tabulated as each TDM was analyzed and defined in detail. Flight experiments were recommended to validate onorbit any precursor activities, technology development or servicing hardware/equipment, associated with servicing needs.

During the middle period of the contract, the study team made an evaluation of the candidate STS flight experiment data base and selected seven experiments for expanded definition as shown on Figure 7.4-2. The study team enlisted Denver Aerospace Technical Operations to expand the definition of these flight experiments to include; technical approach, equipment requirements, schedule and funding. An example of the expanded STS flight experiment/definition is the Storable Fluid

Fluid Transfer

Cryogenic Fluid Storage Tank/Offload to S/C	1987-8
Transfer OTV Storage Tank to Orbit/Resupply OTV	1992-3
Propellant Delivery to Orbit-ET//ACC/OMS Capture	1986-7
Hydrazine Transfer-Cargo Bay	Planned
PH-1/Mark II Fluid Transfer	Planned
Checkout of Standard Propellant Transfer Interface Module	1985-6
Earth Storable Storage Tank/Offload to S/C	1985-6
Propellant Delivery to Orbit-ET/ACC/OMS Capture	
Cryogenic Fluid Management Facility Tests	Planned

OMV

OMV/Space Station Proximity Flight Control	1986-91
Space Station Assembly Demonstration	1987-88
Formation Flying with the Space Station	1980-91
OMV Docking and Berthing Development	1991-92
OMV/OTV Servicing Demonstration in Space Refueling/Mating	1992-93
Space Station Platform Refueling Demonstration	1 88-9
Tethered Fuel Depot Demonstration	1990-91
Space Station Orbiter Docking Demonstration	1988
Aft Cargo Carrier Retrieval Demonstration	1989-90
Space Station Contamination Evaluation	1987-8
OMV Refurbishment/Checkout Demonstration	1989

Servicers

OMV/Servicer Mating Demonstration	1989-90
OMV/Servicer Module Changeout	1991-2
OMV/Servicer Propellant Transfer	1991-2
OMV/OTV Refurbishment Demonstration	1989-91
Resupply of Materials Processing System at Remote Locations	1990
Validate all Servicing Activities anticipated for Typical Repair/Refurbish Missions (AXAF, GRO, ST)	1991
Test of General Purpose Spacecraft Servicer (Payload Carriage/Carousel Mechanism and General Purpose Tools)	1992-3

<u>Space Station Assy Modification</u>

Space Station Service Area/Track/RMS Demonstration	1989-90
Deployment, Growth, Maintenance Demonstrations	1988-9
Assembly, Growth, Maintenance Demonstrations	1988-9
Transfer, Large Body Dynamics Tests	1988-9
Validation, Servicing (Aerobraking, Propulsion, Power Systems)	1988-9
MMU, EMU, OMV, OTV Outgassing Evaluation - Use Trailing OMV to Measure	1987-90
Control Method Evaluation - Cleaning, Cold Traps, Purge Concepts	1988-9

<u>Spacecraft On-Orbit Assy</u>

On-Orbit Validation of Spacecraft Assembly Tools	1989

<u>Mating/Docking</u>

Validation of OMV/Spacecraft Stacking	1989-90
Validation of Demating of OMV/Spacecraft, Demating in Vicinity of STS	1989-90

Figure 7.4-1 STS Flight Experiments

- 7 STS FLIGHT EXPERIMENTS SELECTED FROM 37 CANDIDATES
  - CONSULTED TECHNICAL SPECIALISTS
  - DEFINED DRIVING TECHNOLOGIES FOR SPACE STATION SERVICING
- STS FLIGHT EXPERIMENT COMPLEMENT:
  - SPACE STATION PROX OPS AND DOCKING/BERTHING DEMONSTRATION
  - SPACE STATION CONTAMINATION INVESTIGATION
  - STORABLE FLUID MANAGEMENT DEMONSTRATION REFLIGHT
  - PROPULSION MODULE REFUELING DEMONSTRATION
  - SERVICER MODULE CHANGEOUT DEMONSTRATION
  - SERVICER PROPELLANT TRANSFER DEMONSTRATION
  - TETHERED ET DEORBIT DEMONSTRATION

Figure 7.4-2 STS Flight Experiments

Management Demonstration (SFMD) reflight. The initial flight of the SFMD equipment is still scheduled for an STS flight in 1984. The existing SFMD facility is shown in Figures 7.4-3 and 7.4-4, and represents an opportunity to test many fluid transfer and propellant tank technologies that would directly support Space Station servicing. The initial SFMD experiment involves fluid transfer tests using a capilliary-type propellant management device (PMD), consisting of screen covered channels and cells formed by barriers and baffles. The equipment list, cost and schedule estimates for the recommended SFMD reflight is shown on Figure 7.4-5. The reflight would test another capilliary-type PMD device. This PMD has a sheet metal structure that uses the surface tension of the liquid in crevices of the structure to position liquid over the tank outlet. This device has the potential to allow venting of the tank as it fills. The experiment would examine the static liquid orientation, sensitivity of the liquid to disturbances, and performance during refill and expulsion.

7.5 Technology Development and STS Flight Experiment Plan

The Technology Development and STS Flight Experiment Plan, hereafter referenced as the TD&FE Plan, is a time phased sequence of technology development and flight validation activities leading to development of servicing capabilities. The genuine development of such a plan is considered well beyond the scope of this contract. However, the technology development data base and the STS flight experiment data, combined with additional estimates of required Space Station flight experiments has provided information enabling the generation of realistic outlines of a TD&FE Plan. An example of this plan is shown on Figure 7.5-1. This plan highlights the top level technology activities essential to demonstration of TDM 2, the retrieval and repair of the Advanced X-ray Astrophysics Facility. It addresses technology related to three of the seven areas identified previously in Paragraph 7.3, Technology Development Requirements; i.e., fluid transfer management, the space-based reusable low energy transport vehicle (OMV), and onorbit maintenance, repair and retrofit operations.

For technology development in the area of fluid transfer management, NASA has scheduled the initial flight of a Storable Fluid Management Device (SFMD) on an upcoming STS flight. This is an aft flight deck experiment consisting of two tanks, a supplier and receiver tanks with visible panels to observe and photograph fluid transfer operations under varying conditions. Follow-on flights for the SFMD are recommended to evaluate other propellant management devices (PMD) and other fluid transfer technology issues.

A fluid quick disconnect (QD) for onorbit refueling of the Gamma Ray Observatory (GRO) is in planning and will be supplied to the GRO developer by mid-1986. An STS flight experiment will validate the QD. Planning is also underway in NASA for development of a standard propellant transfer interface device. Ground development is expected to begin in 1985, with flight test of a manually connected (EVA) device in 1987, and an automated device flight tested in 1989.

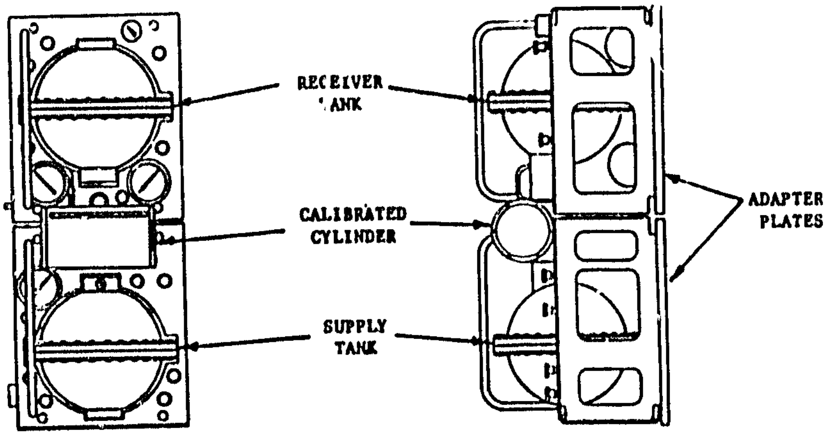


Figure 7.4-3 SFMD Configuration

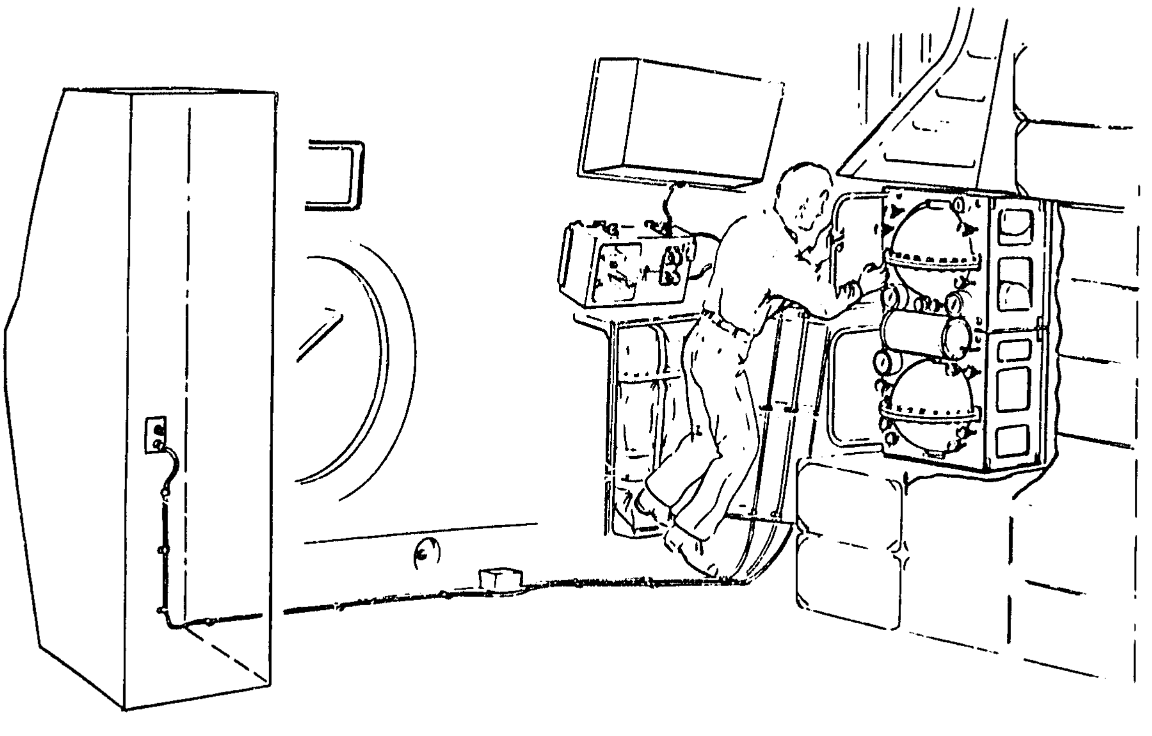
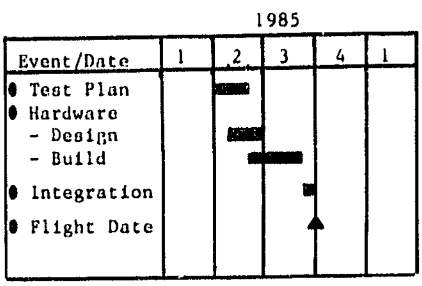


Figure 7.4-4 Storable Fluid Management Demonstration - Orbiter Mid-Deck

EQUIPMENT:
- STS ORBITER
- SFMD
- NEW CAPILLARY DEVICE
  - SHEET METAL STRUCTURE TRAPS LIQUID IN CREVICES WITH SURFACE TENSION, POSITIONS OVER TANK OUTLET
  - POTENTIAL TO ALLOW VENTING AS TANK FILLS

SCHEDULE AND FUNDING:



1985 - $0.3M
TOTAL $0.3M

Figure 7.4-5 Storable Fluid Management Demonstration - Reflight

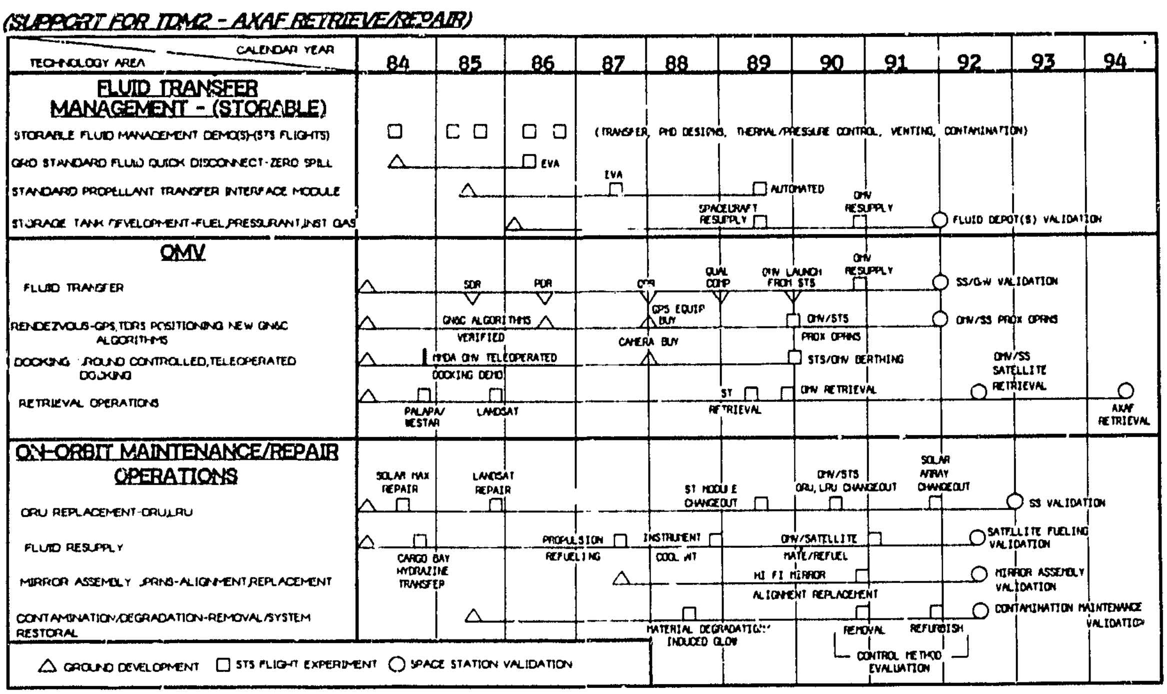


Figure 7.5-1 Technology Development and STS Flight Experiments Plan

For OMV, the present development schedule is shown and fluid transfer tests are not required prior to flight test in 1990. An OMV resupply flight experiment is scheduled during 1990. The schedule for rendezvous and docking ground development, STS flight tests and Space Station validation tests are also provided. In addition, retrieval operations are scheduled, beginning with PALAPA/WESTAR later this year, including LANDSAT and SPACE TELESCOPE, all by STS. An OMV retrieval is scheduled with first launch from STS, with validation flights at Space Station, following completion of OMV accommodations on Space Station.

Onorbit maintenance and repair technology schedule includes development and validation of ORU replacement operations, fluid resupply, mirror assembly replacement (for AXAF), and contamination/degradation removal and system restoral operations. Fluid resupply development is already underway and an STS cargo bay hydrazine transfer is scheduled by NASA for later this year. The Mark II propulsion transfer experiment, previously discussed, is recommended for STS flight in 1987. Following development of OMV and OMV tanker kits, an OMV/satellite refueling is scheduled in 1991.

In general, all technology development trails lead to a series of appropriate STS flight tests, and Space Station validation tests prior to servicing of AXAF in 1994.

8.0 PROGRAMMATIC ANALYSIS

The programmatic analyses for Phase 2 of the servicing study included; development of a summary TDM schedule, an evaluation of the cost of each TDM, and finally, an estimate of the spread of costs across the summary TDM schedule.

8.1 TDM Schedule

The TDMs were scheduled independently, using realistic technology development schedules and existing program planning schedules including those for Space Station, OVM, OTV, AXAF, EOS, and LDR. The TDM schedule is displayed on Figure 8.1-1. The test bed role of the Space Station as a base for demonstrating evolutionary satellite servicing capabilities is strongly supported by this schedule.

Space Station modification, TDM 3 is the first of the five selected TDMs scheduled for implementation. Planning for any TDM assembly operation involving modification of the Space Station will be initiated early in Space Station definition efforts, and will include tracking of all identified precursor activities. The scheduled mission is expected to be conducted during the latter phase of evolution leading to an IOC.

TDM 1 is the second scheduled mission and will take place following Space Station development, Materials Processing Platform development and validation of OMV front end servicer kit operations. The late 1993 schedule for this TDM appears reasonable and realistic. It can be scheduled earlier if the requisite precursor activities are complete.

TDM 2, the AXAF retrieval and repair mission, could be conducted early, as described previously, if precursor activities are completed, and major malfunctions occur in an orbiting AXAF system. Otherwise, the mission will be conducted per the present AXAF program schedule.

TDM 4, the onorbit assembly of the Large Deployable Reflector is presently planned for the 1997 timeframe. The time phasing for TDM5, demonstration of the Intelligent Servicer, is to consolidate evolving automation advances in 1991, and to develop a semi-autonomous, supervisory controlled servicer for demonstration in 1997.

8.2 TDM Cost

The approach used to estimate TDM costs in Phase 2 was: 1) to identify all cost elements for the TDMs, including costs of the Space Station and the systems being serviced, and 2) the narrow scope of cost estimating to those costs specifically related to implementation of the TDM. Costs related to the Space Station and to the satellite system being serviced, such as AXAF and LDR, were not costed, as these elements will be developed independent of servicing TDMs. To estimate each of the TDM specific costs, parametric cost models were used and estimates presented in fiscal year 1984 constant dollars. A final cost display provided was a satellite servicing funding profile, spreading costs across the overall TDM schedule.

Cost analyses were based on the assumptions listed on Table 8.2-1. IVA costs for servicing activities were estimated at $5000 per man hour, and STS crew costs of $17,500 per man hour were used for EVA servicing. Hardware costs were developed using Planning Research Corporation (PRC) cost models. The cost factors are all summarized on the table.

An example of how cost elements were broken out for each of the TDMs is shown on Figure 8.2-1. Costs to demonstrate resupply of the Materials Processing Platform (MPP) are outlined in three cost element categories. MPP unique costs are those related specifically to development and operation of the MPP. It is assumed that the EOS MPP will be resupplied by the STS prior to evolution to Space Station servicing use. A second cost element category was the common costs directly related to Space Station, such as development of satellite servicing elements, including a servicing hangar, OMV, OMV berthing, and a fueling depot. These elements will be used by all related initial TDMs and following servicing users, and are not specifically included as TDM costs specific to TDM1. These include training for the mission, engineering and technical support, OMV fuels and refurbishment and crew time. The estimated cost of TDM1 is $7 million.

A final step in the cost analysis was to provide a funding profile for TDM costs applied across the 7-8 year schedule of TDM activities. The spread of TDM costs is shown on Figure 8.2-2. Cost drivers, as would be expected, are TDM3 and TDM5. TDM3, assembly of the Space Station servicing support area, is an immense operation. It requires massive outlays for assembly training activities, and for performance of the mission. It is lengthy and time consuming as defined in this study. TDM5 cost drivers include development of the Intelligent Servicer and training related to its use. The cost of both training for mission performance and for the Intelligent servicer are all allocated to this mission. If proper estimates of the frequency of use of the servicer could be made, proper allocation of expenses related to this mission would significantly reduce its cost.

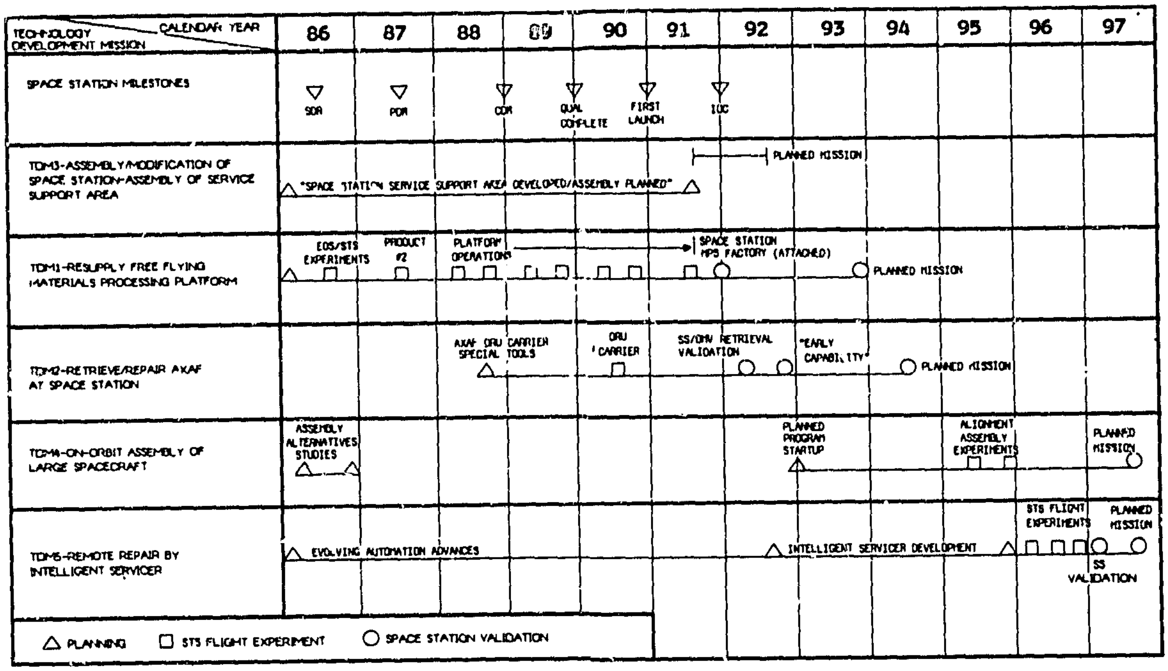
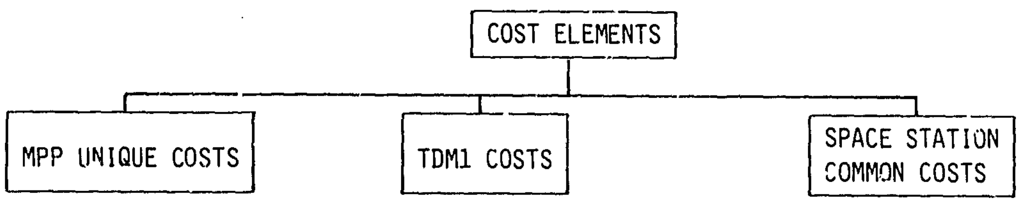


Figure 8.1-1 TDM Schedule



MPP UNIQUE COSTS

- MODULES
- MODULE TRANSPORT (FROM/TO GROUND)
- MODULE STORAGE
- MODULE RESUPPLY SERVICER
- SERVICER BERTHING FACILITY
- RMS ON MPP
- MPP WITH TEMPORARY STORAGE RACK
- COMMUNICATIONS EQUIPMENT (ON MPP)
- PLANNING FOR MPP SERVICING IS MPP COST

TDM1 COSTS

- TRAINING FOR MISSION
- ENGINEERING AND TECHNICAL SUPPORT
- OMV REFURBISHMENT
- SPACE CREW TIME
- OMV OPERATIONS (FUEL USAGE)

SPACE STATION COMMON COSTS

- OMV REFURBISHMENT FACILITY
- OMV BERTHING FACILITY
- OMV FUEL DEPOT
- OMV OVERHAUL
- OMV SUPPORT EQUIPMENT
- RMS
- UMBILICALS
- MONITORING EQUIPMENT
- HANGAR FACILITY

Figure 8.2-1 TDM 1 Resupply Free-Flying MPP

Table 8.2-1 Satellite Servicing Cost Analysis

BASIC GROUND RULES AND ASSUMED COST FACTORS:

- 1984 $ IN MILLIONS
- SPACE STATION CREW OPERATING COSTS (IVA) BASED ON A SPACE STATION CREW OF 6 AND AN OPERATING COST OF $30,000/HR
- EVA CREW COSTS TAKEN FROM STS USER'S GUIDE - ASSUMED TO BE $17,500/HR/MAN
- HARDWARE COSTS DEVELOPED USING 1978 PRC SPACE STATION COST MODEL
- STS COST/FLIGHT ASSUMED AT $200M
- OMV FUEL ASSUMED TO BE STS DELIVERED AT A COST OF $2,000/LB
- SPACE CREW TRAINING IS ASSUMED AS A FUNCTION OF HARDWARE DDT&E AND PRODUCTION COSTS - FUNCTION IS GIVEN BY '78 PRC MODEL

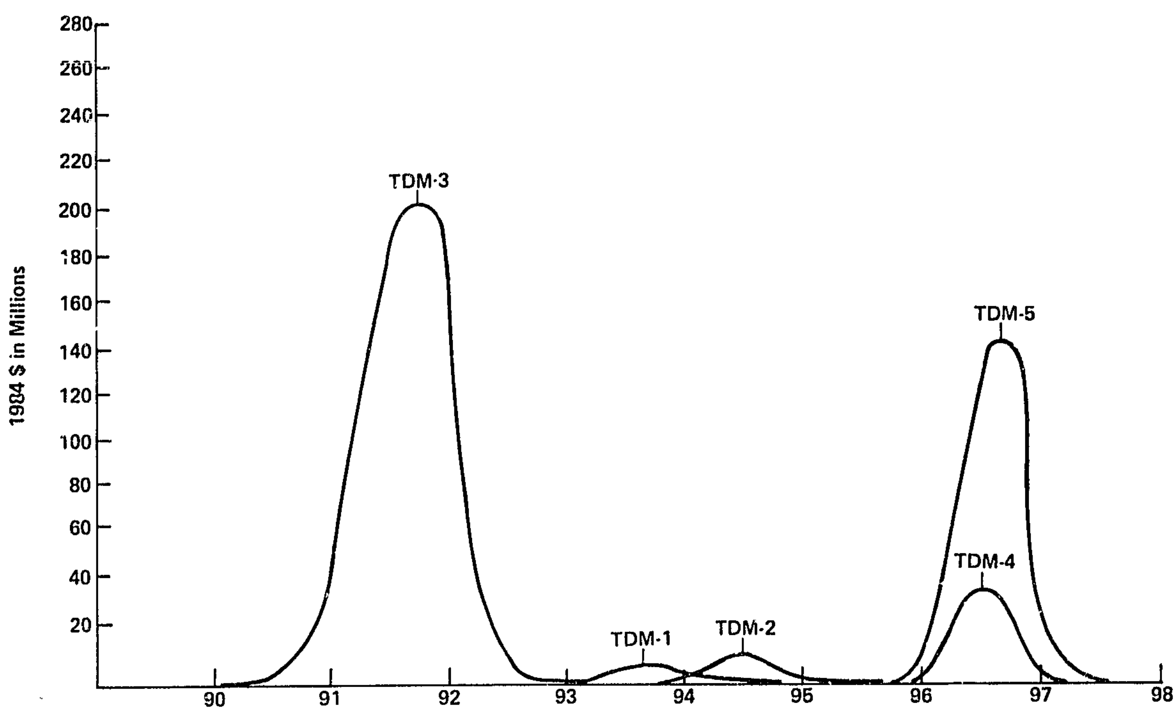


Figure 8.2-2 Satellite Servicing - TDM Funding Outlays

9.0 INDUSTRIAL SERVICING INTEREST ASSESSMENT

9.1 Introduction

The objective of this task was to determine the interest of potential commercial Space Station users in the services to be demonstrated on the early Space Station. The planned approach to this task was: 1) to develop a comprehensive overview of the cost, timing and capabilities that would be demonstrated by the TDMs, 2) to contact potential commercial space users and discuss study results; i.e., conceptual Space Station satellite servicing concepts, and 3) to determine commercial user needs and assess their interest in developing and using servicing capabilities at the Space Station.

Upon completion of all of the tasks previously discussed, a selected group of potential commercial users, and others presently involved in studying concepts for commercialization of space, were contacted. This group of commercial user contacts is displayed on Table 9.1-1. The results of the commercial user assessment were generally very positive. Potential users expressed genuine awareness of and interest in the potential available at Space Station, and presented concerns and questions that will assist Space Station servicing planners in developing servicing capability. The results of two of the commercial user inquiries will be presented as examples of this activity. The first of these is outlined in Table 9.1-2.

Ford Aerospace is presently performing a study for Lewis Research Center (LeRC) examining potential designs for commercial payloads to be attached to a commercially operated geostationary earth orbiting (GEO) platform to be available in the late 1990s. Both the GEO platform and the potential attached payloads are intended to be operated by commercial sources. Following initial discussions, it became clear that their principal servicing interest was to determine whether to configure the commercial payloads for extended life or design them for servicing.

Ford's primary concern related to the question of whether the capability to conduct retrofit operations, to accommodate new operational or technological improvements, into existing payloads would exist in the late 1990s. Ford believes that for communication payloads, for example, user coverage patterns will change, requiring smaller beamwidths. Thus, in turn, will require new feed assemblies and changeout of wave guide interconnects. They also envision higher power amplifiers and the need to replace these onorbit. Ford expressed the need for data on design criteria for servicing and the need for servicing cost estimates and data for cost tradeoffs to determine whether to configure for servicing.

It is clear that Ford believes potential commercial payload designers will focus on the importance of being able to cost-efficiently design for and be provided retrofit servicing capability in the late 1990s. Ford believes commercial platform payload users will support servicing, however, they will require near term data on servicing design criteria and costs to enable conduct of trades related to servicing.

Table 9.1-1 Commercial Satellite Servicing Assessment - Contacts

FIRM	*COMMERCIAL INTEREST*
FORD AEROSPACE	COMMERCIAL GEO COMMUNICATIONS PLATFORM, COMMERCIAL GEO PAYLOAD DEFINITION
JOHN DEERE & CO	SPACE IRON PROCESSING
LOCKHEED MISSILE & SPACE CORPORATION	COMMERCIAL GEO COMMUNICATIONS PLATFORM
McDONNELL DOUGLAS ASTRONAUTICS CORPORATION/ JOHNSON & JOHNSON ORTHO DIVISION	ELECTROPHORESIS OPERATIONS IN SPACE
MIRCOGRAVITY RESEARCH ASSOCIATES	ELECTROEPITAXIAL GROWTH OF GALIUM ARSENATE CRYSTALS
MINNESOTA MINING AND MANUFACTURING	ORGANIC & POLYMER CHEMISTRY
RADIO CORPORATION OF AMERICA	COMMERCIAL GEO PAYLOAD DEFINITION
WYLE LABORATORIES	COMMERCE LABORATORIES

Table 9.1-2 Servicing Interest - Assessment

FIRM : FORD AEROSPACE

PROGRAM : COMMERCIAL GEO COMMUNICATIONS PAYLOAD DEFINITION

SEVICING INTEREST: DETERMINE WHETHER TO CONFIGURE PAYLOAD FOR EXTENDED LIFE OR DESIGN FOR SERVICING

FORD QUESTIONS

- WILL OPERATIONAL/TECHNOLOGY RETROFIT SERVICING CAPABILITY EXIST IN LATE 1990'S?
  - USER COVERAGE PATTERNS WILL CHANGE, REQUIRING SMALLER BEAMWIDTHS, NEW FEED ASSEMBLY, WAVE GUIDE INTERCONNECT
  - DEVELOP HIGHER POWER AMPLIFIERS, REPLACE ONORBIT
- NEED DATA ON SPACECRAFT DESIGN CRITERIA – HARD POINTS, THERMAL ENVIRONMENTS DURING TRANSPORT AND RETROFIT, IMPACT FORCES
- BASIS FOR COST TRADEOFFS INVOLVING SERVICING
  - SERVICING COSTS FOR RESUPPLY, RETROFIT

MARTIN MARIETTA ASSESSMENT

- USER KEYS ON IMPORTANCE OF RETROFIT, UNDERSTANDS HIS POTENTIAL TECHNOLOGY/OPERATIONAL SERVICING NEEDS
- USER IS PREPARED TO SUPPORT SERVICING, REQUIRES NEAR TERM DATA ON SERVICING DESIGN CRITERIA AND COSTS

A second and final example of commercial user assessment is the MDAC Electrophoresis Operations in Space (EOS), presently a joint endeavor with NASA, outlined in Table 9.1-3.

In the case of many of the concepts which have been advanced to date in the field of space manufacturing, neither the market economics nor the technological approaches have as yet been fully validated. In fact, few of these have matured to the point of flight demonstration. One of these is the Electrophoresis Operations in Space (EOS) program, which represents a Joint Endeavor Agreement between NASA and the McDonnell Douglas Astronautics Company (MDAC) and its teammate, the Ortho Division of Johnson and Johnson. The EOS team has conducted 5 STS experiments and is planning for operations both on free flying spacecraft/platforms and for operations at the Space Station.

The study team communicated with McDonnell Douglas and found their servicing concerns to be more specific then others as a result of the maturity of program planning. For operations on the Space Station, they are trying to understand how very large replacement modules (10 feet long, 12,000 pounds), can efficiently be transported to the Space Station. They are looking at shared flights with a Space Station logistics module. MDAC is also concerned with the large power service support requirements at Space Station. They are also examining design criteria for resupply, for accommodation needs for module storage at Space Station and, of course, for the cost of these services.

The free flyer operations questions are similar in nature. One additional question related to the availability of OMVs for expansion of module delivery and retrieval operations at an increasing number of free flying materials processing platforms.

The servicing interest of this customer is high and MDAC is planning to conduct servicing at and from the Space Station. The servicing needs are clear for the EOS program. It could serve as an excellent model for customer accommodations requirements on the Space Station, and as an initial user of OMV front end kits.

Table 9.1-3 Servicing Interest - Assessment (Concl)

FIRM : McDONNELL DOUGLAS ASTRONAUTICS COMPANY (MDAC)

PROGRAM : ELECTROPHORESIS OPERATIONS IN SPACE (EOS)

SERVICING INTEREST: OPERATIONS SUPPORT THROUGH RESUPPLY OF PROCESSING FACTORY MODULES

MDAC QUESTIONS

- FOR OPERATIONS AT SPACE STATION
  - SHARED FLIGHTS WITH LOGISTICS MODULE? 10 FOOT LONG, 12,000 LB REPLACEMENT MODULE
  - POWER SERVICE SUPPORT- 12-15 KW/MODULE REQUIRED
  - DESIGN CRITERIA FOR RESUPPLY, MODULE STORAGE AT SPACE STATION
  - COST OF SERVICE
- FOR FREE FLYER OPERATIONS
  - MODULE STORAGE AT SPACE STATION
  - DESIGN CRITERIA FOR RESUPPLY
  - OMV FLEET SIZE ADEQUACY
  - COST OF SERVICING

MARTIN MARIETTA ASSESSMENT

- CUSTOMER PLANNING ON SERVICING
- EOS ONE OF MOST MATURE COMMERCIAL SPACE VENTURES, TOP LEVEL NEEDS CLEAR TO USER
- EOS CAN SERVE AS EXCELLENT MODEL FOR CUSTOMER ACCOMMODATION REQUIREMENTS ON SPACE STATION, DRIVER FOR OMV FRONT END KITS
- PREPARED TO PAY REASONABLE COSTS FOR SERVICING

10.0 SUMMARY OF STUDY CONCLUSIONS

The MSFC Satellite Servicing study, conducted over the past two years by Martin Marietta has supported development and refinement of the satellite servicing needs at Space Station. Specifically, study results were periodically presented to the Space Station Concept Development Group(s), and to the Satellite Servicing sub-group.

Study conclusions for Phase 2 are summarized below:

a. The five TDMs selected and defined during Phase 2, if implemented, would demonstrate the highest priority servicing capabilities required at the early Space Station. In addition, these same five TDMs would present over 50% of the generally accepted servicing tasks identified during Phase 1&2 for satellite servicing.

b. The selection of specific operational or planned missions, such as AXAF and LDR, and the use of existing (MMU, EVA) and planned servicing support elements (OMV/OTV), greatly increased the clarity of Space Station servicing requirements/accommodation needs definition.

c. The TDM detailed definition efforts, including functional/operational analyses, have demonstrated the feasibility of conducting even the most complex of tasks at the Space Station. This study task also identified the most challenging of these tasks, including onorbit assembly of adaptive mirror segments, enabling a proper focus on technology development needs.

d. The identification of servicing technology development requirements will support planning for Space Station satellite servicing technology initiatives presently under consideration.

e. The STS will provide a vital link in validating servicing technology, Space Station servicing elements and servicing support equipment. Planning for servicing should include considerations for STS flight experiments.

f. The performance of TDM operational analyses has revealed a growing list of standard STS servicing tools and equipment being developed for planned missions. A high percentage of these and follow-on developments, can be transitioned to and used at Space Station.

g. Servicing cost analyses continue to support the concept that the total cost of initial servicing demonstrations (TDMs) can be reduced by using existing or planned satellite systems - GRO, ST, AXAF, LDR.

h. The assessment of commercial servicing interest resulted in a firm conviction that most planners were considering at least one aspect of servicing. There were specific questions relative to availability and cost of servicing. Potential users should be assured that their current questions and concerns are being or will be addressed in a timely manner. This can only stimulate continuing interest and support for servicing at and from the Space Station.